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EFFECTS OF SOME BIOLOGICAL AND MECHANICAL FACTORS AFFECTING TUBER DAMAGE

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled EFFECTS OF SOME BIOLOGICAL AND MECHANICAL FACTORS AFFECTING TUBER DAMAGE submitted by Richard C. Mills in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE .

ABSTRACT

The objective was a laboratory study to determine the effect of tuber temperature at harvest on tuber damage and the interaction of temperature with some of the other biological and mechanical factors known to affect tuber damage. A double split plot factorial design was used with tuber maturity in blocks, tuber temperature in the main plots, drop heights in the sub plots and the weight of the tuber randomized in the sub - sub plots with six of the popular Alberta cultivars. The results indicate, that although cultivars vary in tuber damage according to their cultivar characteristics most exhibit a minimum damage in a temperature range not far from freezing.

In general, tuber maturity increased the resistance to tuber damage. Whereas increased weight and drop height increased tuber damage. The temperature did not appreciably affect tuber damage at the lowest and the highest levels of drop height but at the mid level an optimum temperature was quite evident.

Acknowledgements

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1. INTRODUCTION

Mechanical injury is the cause of any damage to the potato tuber other than disease, insects and growing conditions (Alberta Agriculture(3). The most prevalent type of injury is bruising which occurs during harvesting and handling operations. Severe damage such as cuts, cracks and crushing are obvious at harvest time and adversely affect the grade. Slight damage on the other hand is not so apparent at harvest but the effects become evident in storage.

Potato growers suffer a considerable loss in revenue due to mechanical injury. Nearly 20% of the potato crop is mechanically injured at harvest and of this about 4% is graded out. The remaining 16% stays in storage and are unfit for sale to the consumer or the processing industry. According to the Alberta potato commission(2), a farmer who grows 100 hectares (250 acres) of potatoes at an average yield of about 25,000 kg/hectare (250 cwt./acre) loses about $18,000 due to mechanical injury. In 1979, 6,600 hectares (16,500 ac.) were under potato cultivation in the Province of Alberta and mechanical injury accounted for about 1 1/4 million dollars of loss in revenue to the potato producers.

Many factors have been identified as the cause of this high mechanical damage. One of them is the temperature at

harvest. The objective of this study was to investigate the effects of this harvest temperature and its interactions with some of the other biological and mechanical factors that affect tuber damage on six of the popular Alberta cultivars.

2. LITERATURE REVIEW

2.1 Tuber structure

The potato plant Solanum tuberosum is an annual dicotyledonous plant belonging to the Solanacea family. It is also regarded as a perennial crop because of it's ability to produce vegetatively by means of tubers.

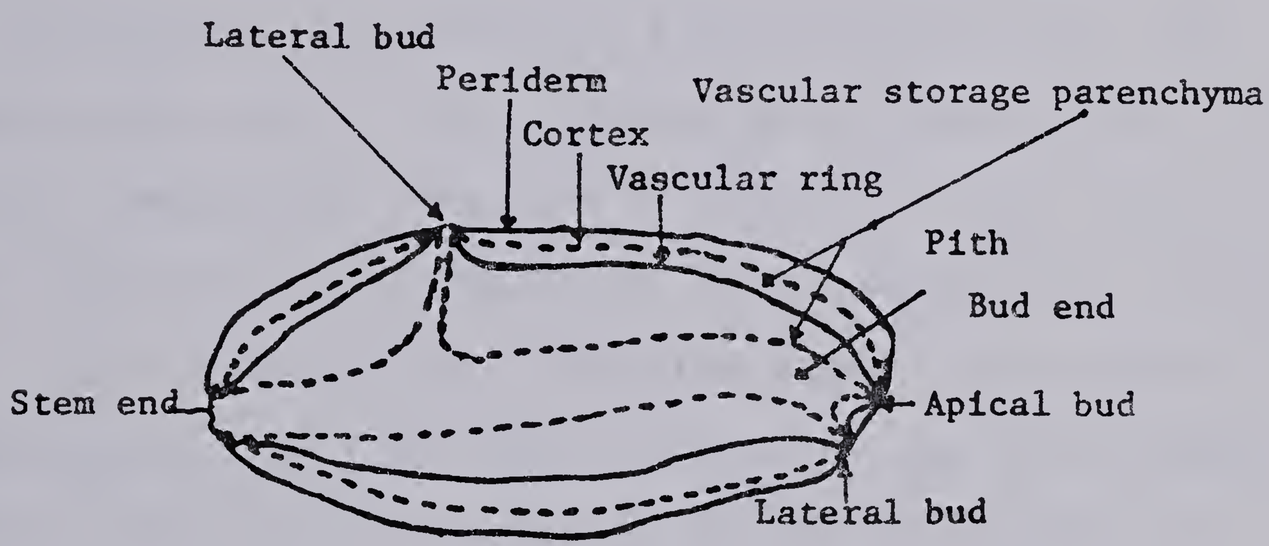

Fig. 1. Structure of the Tuber

The principal zones in the mature tuber (Fig. 1), from the outside towards the centre, are the periderm, cortex, vascular cylinder and the central pith. In general the dimensions of the zones are not well defined because they

vary with growth environment, the cultural practice and the cultivar. Plissey(39) stated that the periderm acts as a protective layer and is about six to ten cell layers thick with each cell about 0.1 to 0.2 mm in diameter; that is, the periderm is about 1mm thick. It is not clear, however, if the periderm and its thickness is the only factor which should be associated with mechanical tuber damage.

2.2 Growth Environment

In general the potato is a cool season crop. For example Jones et.al.(28) recorded an optimum yield in the ambient temperature range of 14°C to 19°C (59°F to 64°F). Tuber shape is also affected by soil temperature. Yamaguchi et.al.(46) observed many irregular shaped tubers when high temperatures prevailed and the moisture was low. Russet Burbank potatoes were extremely knobby when grown at temperatures between 27°C and 30°C (80°F to 95°F). They concluded that shape is more uniform for the temperature range of 16°C to 22°C (60°F to 70°F).

The thickness of the principal zones, and in particular the periderm, is also affected by the soil temperature. For example Harris(19) observed for Russet Burbank potatoes that in the range of 7°C to 10°C (45°F to 50°F) the periderm consisted of 7 to 12 layers of cells, for 18°C to 21°C (65°F to 70°F) it was 9 to 25 layers of cells and for 24°C to 26°C

(75°F to 80°F) it was 10 to 28 layers of cells. With the increase in cell layers was an increase in thickness of the periderm. At still higher temperatures Yamaguchi et.al.(46) observed that the periderm cracked and was divided into patches of thick and thin tissues.

A continuous supply of soil moisture is important in obtaining a high yield and producing a tuber with uniform shape. In some climates this requirement will necessitate irrigation and will be part of the accepted cultural practice. For example Campbell(7 & 8) obtained an increase of 3500 kg./hectare(61 bushels/acre) with the addition of 152mm(6.1 in.) of irrigation water. Blake et. al.(5) reported that the soil moisture should be maintained between 50 and 100% of field capacity. Tuber shape is also adversely affected by a variable supply of soil moisture. Corey and Meyers(12) noted that a knobby second growth is the effect of withholding early irrigation as well as the result of other seasonal factors. The tuber shape and the subsequent damage during harvesting and handling decreased the grade (U.S.) by 17 to 58%. In addition, the withholding of early irrigation decreased the yield by 6 to 30%. Robins and Domingo(41) reported growth cracks on tubers with moisture deficits during the mid season followed by a period of adequate moisture.

The influence of light on the growth and yield of potatoes is determined by the photoperiod. The effect of the photoperiod has been studied by several researchers

including Driver and Hawkes(13), Krug(29), and Bodlaender(6). Because of the effect of soil temperatures, and the correlation between the temperature and the photoperiod, it is not clear if an optimum photoperiod exsists. In general the potato is considered to be a short day plant.

2.3 Cultural practices

Vine killing is a cultural practice which is used to hasten maturity and to reduce tuber disease as well as facilitating mechanical harvesting (Valueva(44) & Hutchinson(23)). Hutchinson(23) indicates that vine killing reduces tuber disease by preventing leaf disease from coming in contact with the tubers. Andrew et. al.(4), in recommending artificial vine killing to the potato growers in Alberta, suggest that in addition to hastening maturity it will increase the dry matter content of the tubers, their quality and prevent discoloration of the stem ends.

Vine killing is accomplished by mechanical or chemical means or a combination of the two. Mechanical beaters (Smith(43)) with flails or chains are used extensively. Sodium arsenite and di-nitro compounds are also applied through conventional low volume spray equipment. For satisfactory results vines are killed 10 to 14 days prior to harvest. Other cultural practices such as planting and

fertilizing, and their effects on tuber shape and size for different cultivars, are beyond the scope of this work.

2.4 Mechanical damage

According to Jarvis(25) unsaleable potatoes are tubers that are green, cracked, mis-shaped, diseased and mechanically damaged, with the last being a high percentage of the total. Although tuber damage is attributed to harvesting it is essential to note that the tuber shape and size are factors which can lessen or aggravate the percentage. Farm Mechanization(14) has stated "When considering potato damage one tends to approach the subject from harvesting as the stage at which damage is done; it is now generally accepted that the reduction of damage does not start at the harvesting operation but at the time of cultivation before the crop is even planted".

Mechanical harvesting of potatoes is common in the industrialized countries using two basic systems (Claves and French (10)). Growers who farm large areas generally use a direct system where the tubers are dug, elevated and transferred into containers or trucks in one operation. With the other system(indirect) the tubers are first dug and windrowed and later are placed in suitable containers. The large grower will pick-up the tubers mechanically while the smaller grower will do this by hand. With the indirect

system (Claves and French (10)) tuber damage during digging and windrowing frequently exceeds the damage incurred during subsequent operations.

McRae(33) reported that a damage survey conducted by the potato marketing board(40) in Britain revealed that 21% of the potatoes reaching storage were damaged. Larsen(30) found that growers in the State of Washington injured 38% of the tubers and of these damaged tubers 12% were such that they affected the grade. Peterson et.al. (37) notes that 65 to 70% of the tubers damaged in Idaho occurred in the field during harvesting. For Colorado, Hansen(18) reports that 40 to 90% of the tubers were skinned, cut or bruised during harvesting. As previously noted, the Alberta Potato Commission(2) estimates that if a farmer grows 100 hectares (250 acres) of potatoes with a yield of 25,000 kg/ha (400 bu/ac) mechanical injury would cost him as much as $18,000. Peterson et. al.(37) concluded that the soil condition, tuber maturity, temperature at harvest and ground speed of the harvest machine are the major causes of the tuber damage.

2.5 Tuber Impact

Green(16) concluded that tuber damage like splits, wounds and bruises appear to be caused by impact with some object. This kind of injury is related to the weight of tuber, the height of fall, and the resilience of the impact surface. A very large tuber such as 500 g (1 1/4 lb) or over is usually damaged. Green(16) also states that for the bulk of the crop, a drop of about 600 mm (24 in.) or less will not cause much damage, but with greater heights the amount of damage will increase substantially.

Parke(34) related the volume of tuber damage to the amount of energy absorbed by the tuber in which the energy absorbed was a function of the impact velocity. He concluded that an impact velocity of 2.3 m/s is required to reach a level of energy absorption such that the tuber is seriously damaged. Since the majority of the harvester chains run below this velocity he attributed the damage to the spinning and bouncing of tubers that he observed. He recommended some design changes, such as aprons which would concentrate the potatoes to the center of the conveyor, to lessen the tuber agitation.

McRae(33) concluded that the damage to tubers by mechanical harvesters is the result of incorrectly set shares, tuber agitation often accompanied by contact with stones the rolling back of tubers and the excessive drop

height into a truck or trailer box. He suggested that the damage can be reduced by improved share design, better depth control and changes in the conveyor or web design.

2.6 Temperature Effects

The effect of harvest temperature is an important factor in tuber damage during harvesting (Johnston and Toko(26)). Lutz et. al.(31), Johnston and Wilson(27) and Schippers(42) are a few among many researchers who have reported a correlation between tuber damage and harvest temperature. Peterson and Hall(35) hypothesized that tuber flesh has viscoelastic properties and is temperature sensitive or thermorheological. Their results with Russet Burbank indicate that temperature affects the susceptibility of tuber bruising in every principal zone. Johnston and Wilson(27) found a linear relationship between bruise resistance and tuber temperature. Their results indicated that an increase of less than 1°C(1°F) in the soil temperature increased the force necessary to bruise the tuber by about 2%. McRae et.al.(32) observed a curvilinear relationship for the British cultivar Pentland Crown. They found that the tuber damage was a minimum between 3°C and 10°C with the optimum or least damage occuring at 8°C. They suggested that further work with many more cultivars is required.

2.7 Cultivar Characteristics

Hudson(22) attributed bruise depths to cell sizes, intercellular spaces and the specific gravity of the tuber. These factors he claimed are characteristics of the cultivar and are not seriously affected by variations in the soil fertility, soil moisture content or soil temperature. He experimented with 11 cultivars and concluded that tubers having low specific gravity, large inter-cellular spaces and large cell sizes are more susceptible to damage. Green(16) examined tuber shapes (a cultivar characteristic) as a factor causing tuber damage and concluded that the oval(ellipsoid) shaped tubers are less susceptible to damage in the field than the round(spheroid) or long(prolate) tubers. He noted that this is due to the tendency of round tubers to roll and consequently they experience greater and more frequent impacts than the oval shaped tubers. On the other hand, long tubers having a round cros section are vulnerable to cuts and bruises on the ends because the contact area of the end is small relative to the total tuber.

2.8 Tuber Maturity

Harvest time varies from place to place and is largely governed by climatic and economic conditions. Research workers (Valueva(44)) and growers have observed that tubers harvested early are more easily damaged than those harvested late. This difference is attributed to the maturity of the tuber at harvest time. The effect of harvest time with respect to the cultivar characteristics and other factors has not been established.

2.9 Storage

The short growing season, particularly in the nothern and southern latitudes necessitates the storage of raw potatoes. Good storage should prevent excessive moisture loss, development of rots, excessive sprouting and large accumulation of sugars. The first 14 days in storage after harvest is termed the curing period because during this time most tubers that are mechanically injured suberize and heal (Andrew et.al.(4)).

Disease, rot and tuber damage at the time of storage can be minimized by providing conditions that promote toughening of the skin and rapid healing of the wounds. Skin toughening is noted by Finney et.al.(15). They report a 30 to 80% increase in impact energy that a tuber can withstand after a 14 day curing period. Hesen and Kroesbergen(21) also found a reduction in the susceptibility to external damage after 14 days of storage but internal bruising increased. Curing occurs most rapidly when the tubers are stored at a temperature of 13°C(55°F) and a relative humidity of 90% for the first 10 to 14 days after harvest. Green(17) stored damaged tubers at 60% relative humidity and 13°C(55°F) in one instance and 8°C(46°F) in another. In the first instance he observed that clean open wounds, such as those caused by the share, or by the breaking away of the knobby second growth, healed satisfactorily. In the second case skin damage did not heal properly and the damage was high. He concluded that a storage temperature of 13°C is better than 8°C to heal clean wounds and skin damage.

2.10 Summary

Though potatoes may be biologically or mechanically damaged or both, the causes of the damage are not independent of each other. Biological damage, such as irregular shaped tubers, may cause a loss of grade. Such

tubers are more susceptible to mechanical damage thereby giving rise to a grade loss. Tubers may be diseased on entering storage and some mechanically damaged tubers may be infected during storage, consequently the percentage of biological to mechanical damage to tubers is unknown. Even so certain cultural practices and growth environment are known to reduce the biological and the mechanical damage. These are the cultivar, maturity, tuber size and temperature. As for the harvestor the main concern is in the drop height and the impact surface. Of particular interest in this study are some of the interactions such as those between tuber temperature and cultvar characteristics, tuber maturity, height of free fall and the weight of the tuber because they have not yet been investigated.

3. EXPERIMENTAL DESIGN AND PROCEDURE

3.1 Factors and Levels

The factors and levels used in this experimental study are listed in table(1) and are as noted in the prior chapter. With regard to tuber maturity two harvest periods were used; early (mid August) and main (early September). The practical problem of obtaining sufficient tubers in each weight class precluded additional harvest periods. Tuber temperature on the other hand did not impose the same restrictions and consequently six levels from 0 to 12°C were used. This temperature range is representative of the climatic conditions frequently encountered in Alberta during the harvest season. The drop heights were arbitarily selected from the range of heights used by McRae(33). As noted above only two weight classes were used because there were not enough large tubers for two of the cultivars for a third class. Also Green(17) concluded that large tubers are usually damaged. The cultivars for the study were selected on the basis of their popularity in Alberta (Alberta Agriculture(1)).

Table 1: FACTORS, LEVELS AND NOTATIONS

FACTORS	LEVELS	NOTATIONS
Period	Early Main	P_1 P_2
Temperature	0°C. 2°C. 4°C. 6°C. 9°C. 12°C.	T_1 T_2 T_3 T_4 T_5 T_6
Drop Height	225mm. 450mm. 750mm.	H_1 H_2 H_3
Weight Class	227g.(1/2 lb) 340g.(3/4 lb)	W_1 W_2
Cultivar	Netted Gem Norgold Russet Norchip Kennebec Warba Norland	V_1 V_2 V_3 V_4 V_5 V_6

3.2 Statistical Design

A double split-plot factorial design with blocks was used in the experiment with the two harvest periods forming the blocks or replicates. This design was required because early and late harvest could not be randomized. The six temperature levels were the split plots and this was necessary because it was not practical to randomize it with the other factors. The three drop heights formed the sub plots to facilitate convenient operation of the drop unit. The two weight classes the six cultivars were embedded in the sub - sub plots.

3.3 Tuber Propagation

The tubers for the experimental work were propagated at the Ellerslie Research Station, of the University of Alberta. The cultivation practices closely followed the recommendations of Alberta Agriculture(4) to minimize disease and other biological damage. To avoid mechanical damage the tubers were hand lifted and adhering soil particles were removed by hand.

3.4 Initial Storage and Sample Selection

The potatoes were sacked as they were lifted and were initialy stored in a conditioning room at 4°C and a relative humidity of 95% (Wigginton(45)). When the harvesting was complete for the harvest period in question, the sacks were removed from the conditioning room. Each tuber was weighed and a selection was made for the two weight classes at room temperature. Three tubers were selected for each level for the purpose of obtaining an average. The tubers selected were typical of the shape of the weight class and the cultivar. The selected tubers were placed in perforated plastic bags, 216 in total (for each harvest), and then stored in the conditioning room to simulate the tuber temperature at harvest.

3.5 Drop Unit

Figures 2, 3 and 4 illustrate the drop unit that was designed and fabricated for this experiment to simulate mechanical damage to the tubers. There are two components to this unit namely the drop mechanism and the impact surface. The drop mechanism (Fig. 4) releases the tubers without any initial velocity. The drop heights were marked on the upright tube to facilitate drop height adjustments.

Fig. 2. Drop Unit

Fig. 3. Impact Surface

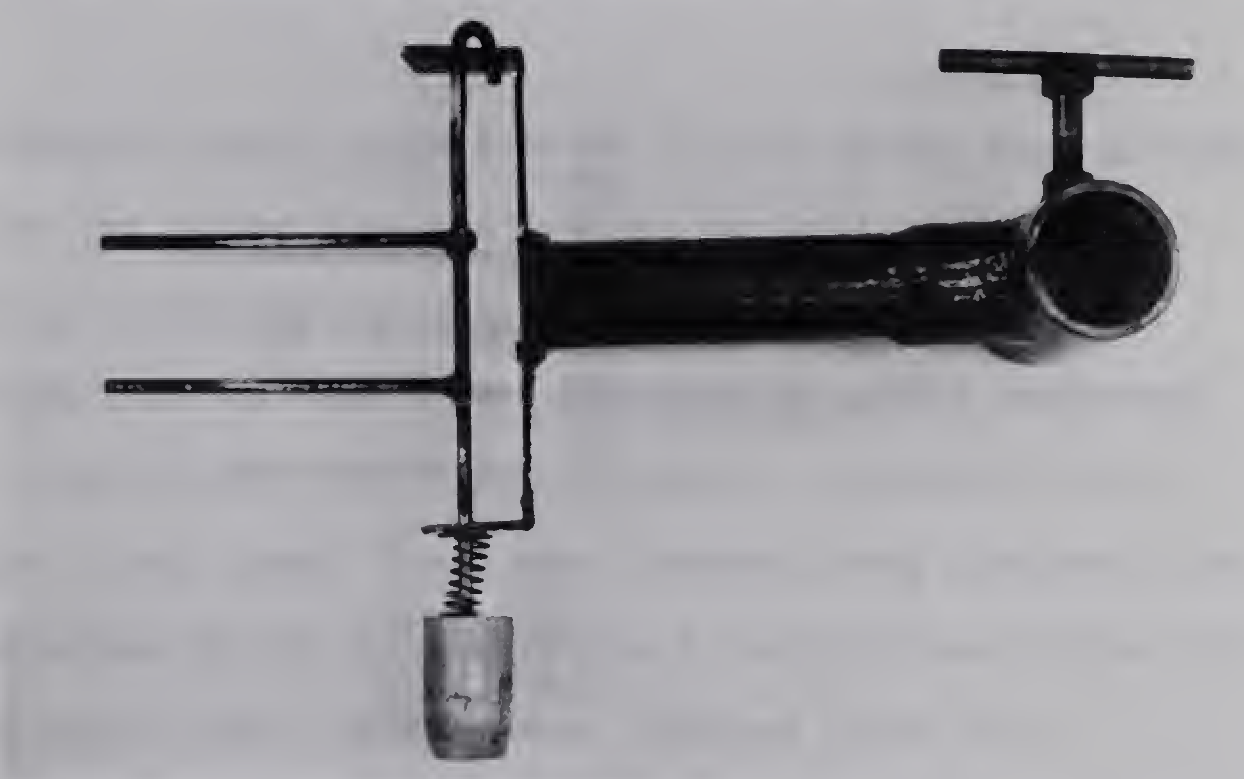

Fig. 4. Drop Mechanism

Two spikes hold the tubers which in turn are fastened to a rod which can pivot about its axis; the axis being in the horizontal plane. The tuber is placed on the spikes which are held horizontally until a small lateral motion releases the catch allowing the spikes to rotate and enabling the tuber to fall.

Impact surface consisted of steel rods 9.2mm (3/8 in.) in diameter welded at intervals of 50mm to represent a typical harvester conveyer. The total impact surface measured 300 x 600 mm (see Fig. 3). The wooden sides of the impact surface prevented the tuber from rolling off the impact surface.

3.6 Harvesting Temperature and Damage Simulation

The bagged tubers were stored in the conditioning room to simulate the tuber temperature at harvest. The conditioning room temperature was set at -1°C and the relative humidity at 90%. Four thermometers were embedded into four tubers (not the bagged tubers) to monitor the tuber temperature. When the tuber temperatures dropped from room temperature to 12°C, the highest temperature chosen for this study sufficient tubers were removed from the conditioning room and subsequently dropped onto the impact surface as detailed in the prior section. The above procedure was repeated for the other temperature levels

(table 1) used in this study for each harvest period. The damaged areas of the tuber were ringed with a felt pen for ease of future identification and the tubers were then rebagged. The damaged tubers were stored for 14 days (Cargill(9)) at 14°C to allow the tubers to go through a healing process.

3.7 Damage Analysis and Observation

After 14 days of storage (at 14°C) for the harvest period in question, samples were examined for damage. Each tuber was cut open and the length, breadth and depth of the damage were recorded (Appendix). These dimensions were multiplied to provide an estimate of the volume of damage (Parke(34)). Using a previously determined specific gravity for each variety and weight class (see table 2) the tuber volume for each weight class was calculated. The tuber volume and the volume damaged noted above were used to compute a percentage damage for each variety and weight class. Tubers that were extensively rotten so that it was impractical to measure the damaged volume and which would soon be totally rotten, were recorded as 100% damage.

Tubers were also assessed for damage on a visual basis using a scale from 0 to 5 (Appendix). Rotten tubers, which were recorded as 100% damage in the prior scheme were classified as having a damage index of 5. Those tubers

without any visible damage were recorded as 0. The other classifications of 1 to 4 are listed in table 3. This assessment of damage closely follows the method adopted by the Europeon Association for Potato Research. In this method, as detailed by Phillipson and Lawrence(38), potato damage is assessed by the number of strokes required by a potato peeler to remove the damaged portion. The peeler removes 1.5mm(1/16 in.) with each stroke. This assessment and its description is also shown in table 3.

Table 2: SPECIFIC GRAVITY OF CULTIVARS

CULTIVAR	WEIGHT CLASS 1 (227g)	WEIGHT CLASS 2 (340g)
Netted gem(V^1)	1.103	1.072
Norgold russet(V^2)	1.066	1.080
Norchip(V^3)	1.093	1.051
Kennebec(V^4)	1.065	1.058
Warba(V^5)	1.075	1.057
Norland(V^6)	1.065	1.054

Table 3: DAMAGE ASSESEMENT

Depth damaged	Description	Damage index	European Association of Potato Research damage assessment
	No damage	0	-
Less than 1mm.	Surface damage	1	Skin damage (less than 1/16 inch)
1mm.-3mm.	Moderately damaged	2	Slightly damaged (1/16 to 3/16 inch)
3mm.-5mm.		3	
More than 5mm.	Severely damaged	4	Seriously damaged (more than 3/16 inch)
	Total Rot	5	-

4. RESULTS AND DISCUSSION

4.1 Analysis of Variance

Analysis of variance was carried out in accordance with the statistical design noted in the prior chapter using a Fortran Program from the Computing services library of the University of Alberta(11). For each main effect and interaction an F-test was carried out. As can be seen in table(4) there are some differences between the damage index and the percentage damage for some of the factors. For example the weight class is highly significant on the basis of the damage index but is not so on the basis of percentage damage.

4.2 Damage Index and Percentage damage

The differences between the two criteria for damage suggested that the correlation between the two should be determined. Results of these calculations are given in table 5 and for the factors of cultivar, drop heights and temperature there are good correlations between the two. Because there are only two weight classes a correlation could not be determined for this factor.

Table 4: *ANALYSIS OF VARIANCE*

Source of variations	Degrees of freedom	Damage Index		Percentage damage	
	N	MS	F	MS	F
Period (P)	1	11.60	30.05**	952.57	26.53**
Temperature (T)	5	3.11	10.20*	89.90	2.50
TP (Error 1)	5	.31		35.90	
Drop height (H)	2	129.32	591.28***	402.77	7.05**
HT	10	1.31	5.99**	59.99	1.05
HP/T (error 2)	12	.22		57.17	
Weight class (W)	1	6.42	35.05***	3.33	1
Cultivars (V)	5	2.53	13.81***	145.04	3.89**
WH	2	.08	1	9.43	1
WT	5	.55	2.98*	93.41	2.50*
WV	5	.51	2.75*	80.59	2.16
HV	10	.31	1.68	52.68	1.41
TV	25	1.41	7.70***	60.85	1.63*
WHT	10	.58	3.16**	98.16	2.63**
WHV	10	.63	3.41***	84.45	2.26*
WTV	25	.50	2.75***	55.60	1.49
HTV	50	.86	4.66***	54.63	1.46*
WHTV	50	.85	4.64***	51.06	1.37
Error 3.	135	.18		37.33	

* *Significant at 5% probability level.*
** *Significant at 1% probability level.*
*** *Significant at .5% probability level.*

Table 5: CORRELATION COEFFICIENTS BETWEEN DAMAGE INDEX AND PERCENTAGE DAMAGE FOR THE MAIN EFFECTS CULTIVAR DROP HEIGHT AND TEMPERATURE

		Mean	Std.Dev.	R^2
Cultivar	Dam.Index	1.826	0.187	0.742
	% Damage	2.309	1.419	
Drop Height.	Dam.Index	1.826	0.948	0.976
	% Damage	2.309	1.672	
Temperature	Dam.Index	1.826	0.208	0.707
	% Damage	2.309	1.117	

4.3 Main Effects

The means of the damage index and the percentage damage for the factors (main effects) are listed in table 6. The reduction, in the case of damage index, is attributed to the maturity of the tubers. As noted in the literature review the tuber damage reduces with the maturity. The large reduction in the percentage damage is attributed to the manner in which the rotten tubers were assessed.

As can be seen in table 6 the tuber temperature at harvest time has an appreciable effect on tuber damage. Most interesting is a minimum damage index in the range of 4° to 6°C. With regard to percentage damage a minimum is indicated at 6°C. These results are similar to those of McRae et.al.(32) in which they obtained a minimum damage for the British variety Pentland Crown at 8°C.

The drop height increased the damage index and percentage damage (table 6). The increase in damage for the increase in drop heights from 225mm to 450mm is three times the rate of increase for the drop height from 450mm to 750mm; that is the increase of drop heights greater than the 450mm did not cause a comparable increase in damage (see figure 5). As for the percentage damage the increase for the first drop height increment is eight times that of the second. McRae et.al.(32), in the absence of specific data, speculated that tubers will not be damaged if the drop

Table 6 : MEANS OF THE MAIN EFFECTS FOR DAMAGE INDEX AND PERCENTAGE DAMAGE

Factors	Levels	Damage index	Percentage damage
Period	Early	2.0	3.79
	Main	1.7	0.82
Temperature	0°C.	2.0	4.27
	2°C.	1.8	1.61
	4°C.	1.6	1.68
	6°C.	1.6	1.14
	9°C.	1.8	2.57
	12°C.	2.1	2.59
Drop Height	225mm.	0.8	0.39
	450mm.	2.1	3.13
	750mm.	2.6	3.41
Weight Class	227g.	1.7	2.22
	340g.	2.0	2.40
Cultivar	Netted Gem	1.8	0.48
	Norgold Russet	1.7	1.46
	Norchip	1.6	1.49
	Kennebec	1.8	2.68
	Warba	2.1	3.52
	Norland	2.0	4.24

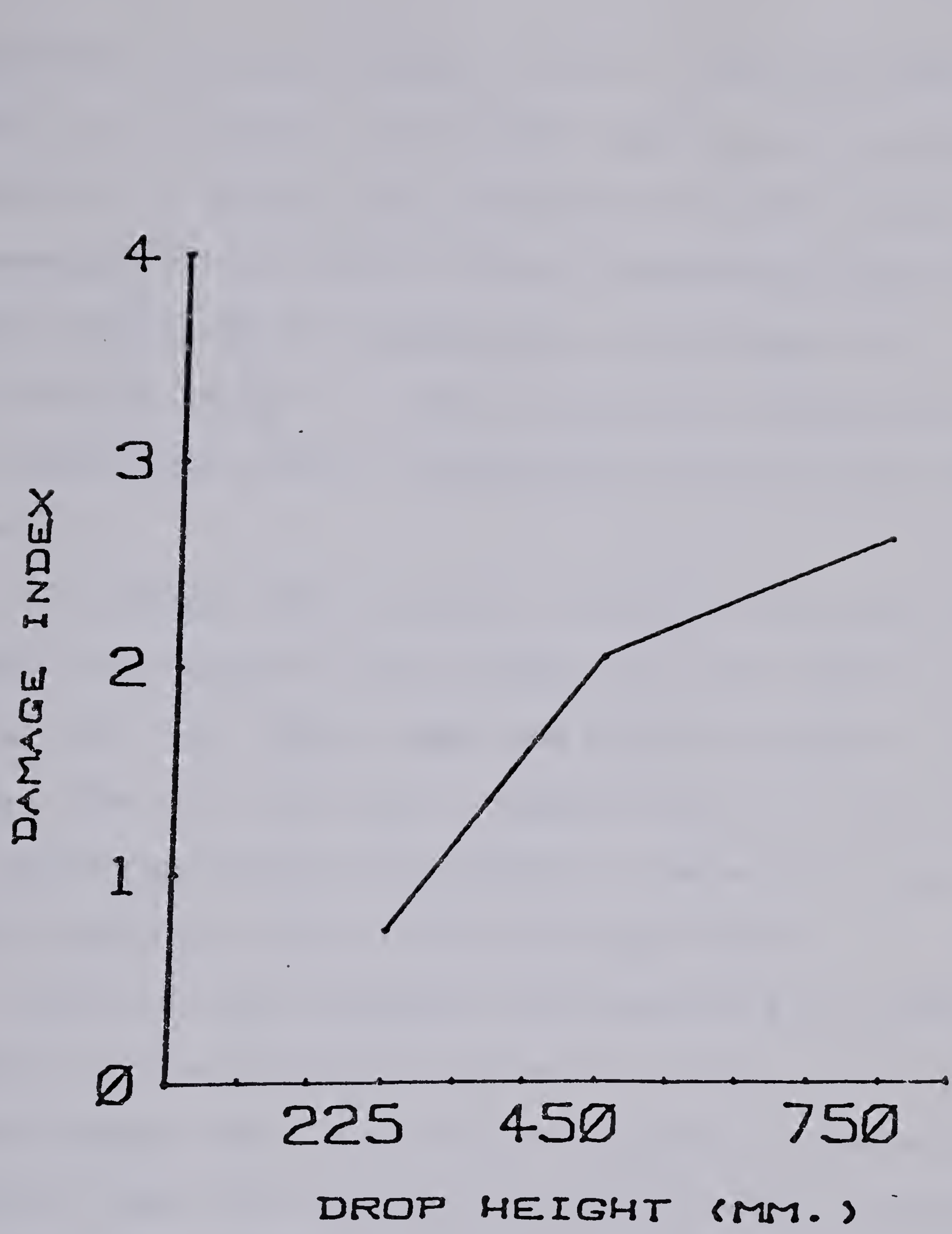

Fig. 5. Drop Height Vs Damage Index

heights are less than 254mm (10 in.). The equivalent drop height to 2.3 m/sec, the maximum impact velocity noted by Parke(34), is 261mm. More conservative still is the recommendation of Alberta Potato Commission(3) that the tubers should not be dropped more than 150mm (6in.). The maximum drop height is complicated by an interaction between the drop height and the temperature which will be noted later.

The damage index (table 6) indicates that the lower weight class sustains less damage than the higher weight class. With the larger tuber the kinetic energy at impact is larger than with the small. Though there is little change in the percentage damage for change in the weight class the volume would be larger with the larger tuber.

There are some important differences with regard to damage for the different cultivars. Norchip scored the lowest damage index and Warba the highest. This was not quite the same for percentage damage in which the Netted Gem cultivar scored the least and Norland the highest. Rotten tubers are the main reason for this discrepancy. The cultivar Norland had far more rotten tubers than the Netted Gem. One of the factors which affect tuber damage is specific gravity. Table 2, however indicates that the differences in the specific gravity are slight. It is apparent therefore that other factors such as different cell sizes may account of the different response for the cultivars.

4.4 Interactions

At the lowest drop height of 225mm tuber damage did not vary much with temperature, but at 450mm the differential response was larger (see figure 6). At the higher drop height of 750mm the differential response to temperature again was small. The reason for this differential response or interaction is not clear. Similarly it is not clear why there is a weight class - temperature interaction(see figure 7). The statistical significance for these two interactions appears to stem from a response of the damage index for a drop height of 450mm and the larger weight class of the tuber (see figure 8). One practical observation from these interactions is that if the drop height can be limited to 225mm or less temperature may not be a factor with regard to tuber damage.

Using a best fit curve technique (Harrison(20)), for the 450mm drop height, a parabolic function produced the largest coefficient of determination for both weight classes (see table 7). The appropriate parabolic functions indicate that the optimum temperature for minimum damage is 6°C (see figure 9).

Figure 10 illustrates the temperature - cultivar interaction and it indicates that cultivars may have different optimum temperatures with respect to minimum damage. For example the indicated optimum temperature for Netted Gem is 4°C whereas it is 9°C for the cultivar

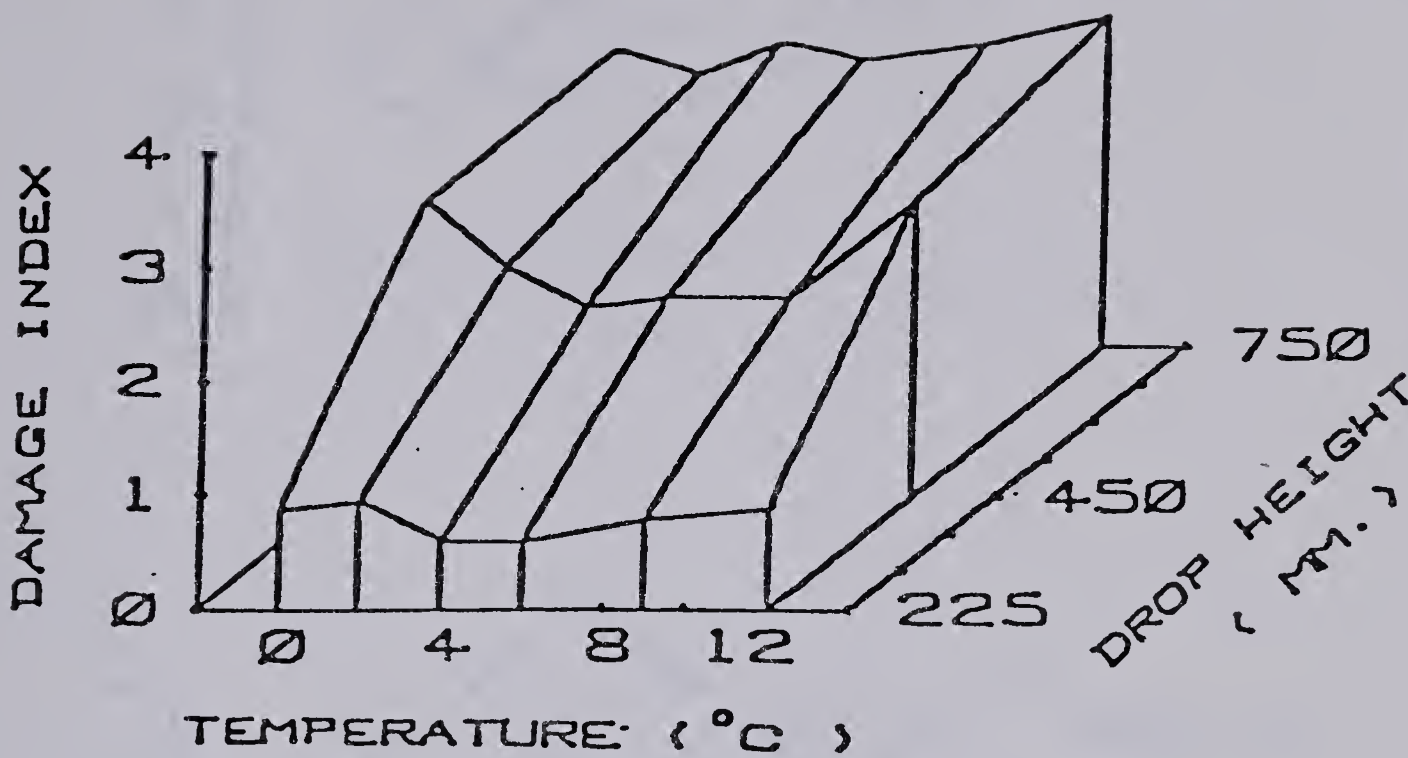

Fig. 6. Temperature - Drop Height Interaction for Damage Index

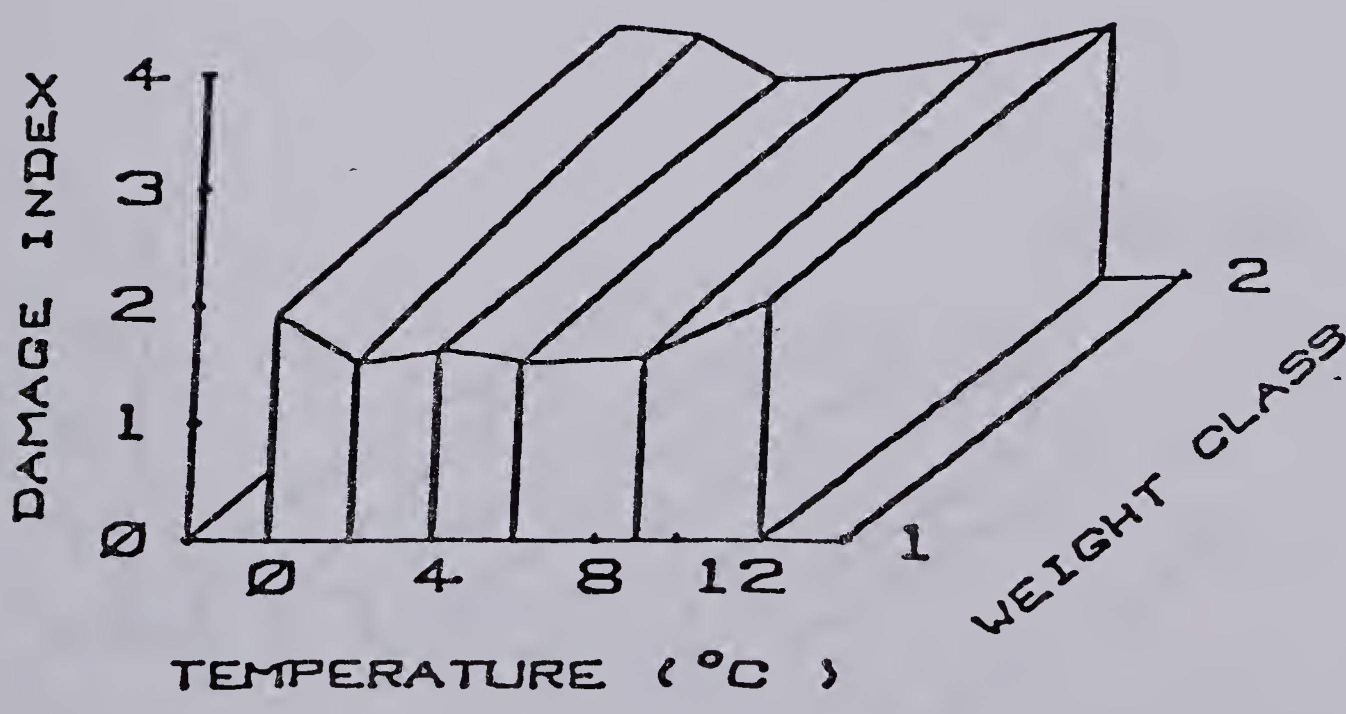

Fig. 7. Temperature - Weight Class Interaction for Damage Index

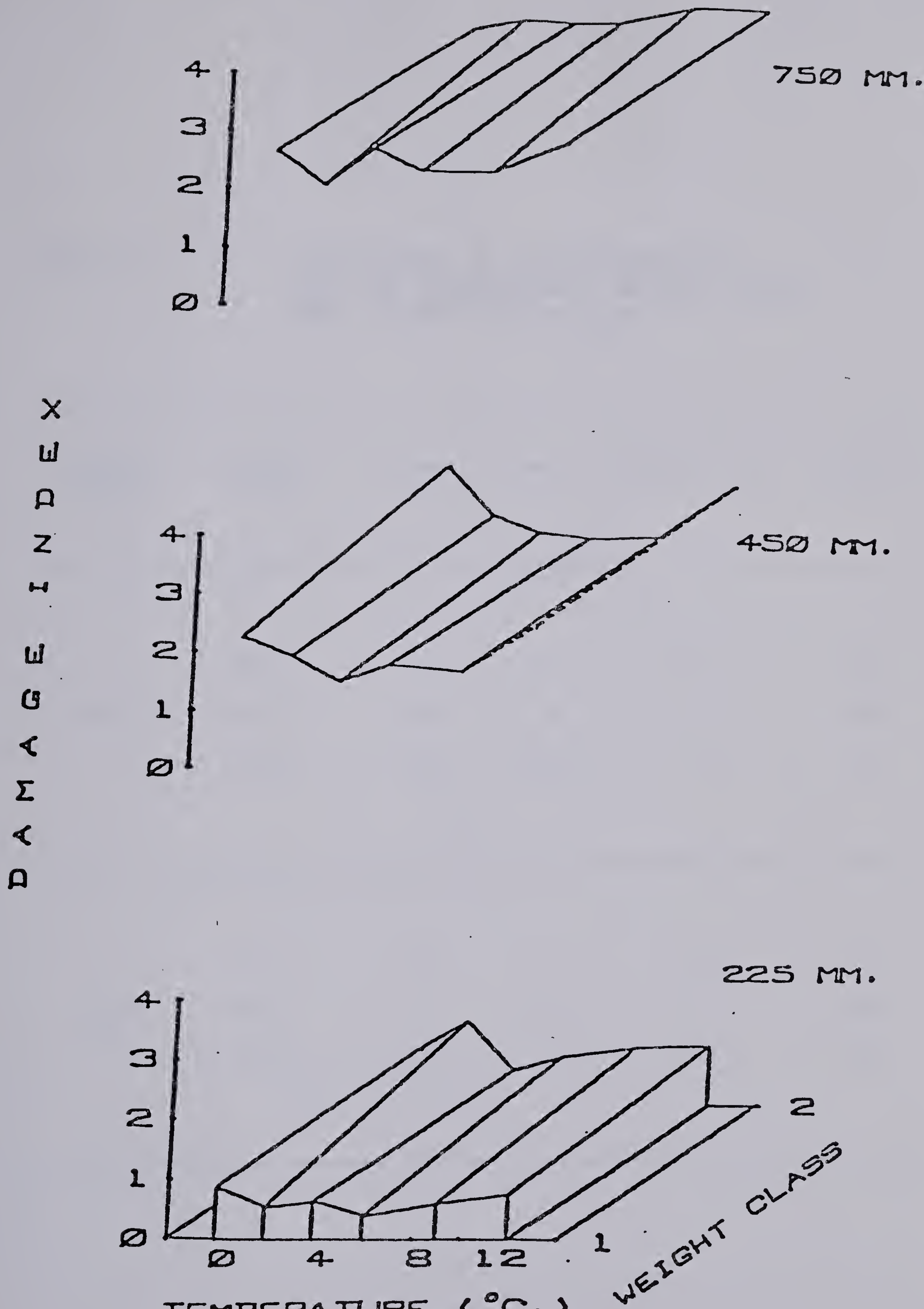

Fig. 8. Temperature - Weight Class - Drop Height Interaction for Damage Index

Table 7: *COEFFICIENT OF DETERMINATION r^2 FOR THE TEMPERATURE - WEIGHT CLASS - DROP HEIGHT INTERACTION*

Weight (g)	Height (mm)	Linear	Power	Exponential	Parabolic
	225	.00	.31	.00	.73
227	450	.06	.14	.04	.88
	750	.13	.04	.13	.38
	225	.00	.00	.00	.11
340	450	.01	.45	.01	.98
	750	.81	.45	.82	.81

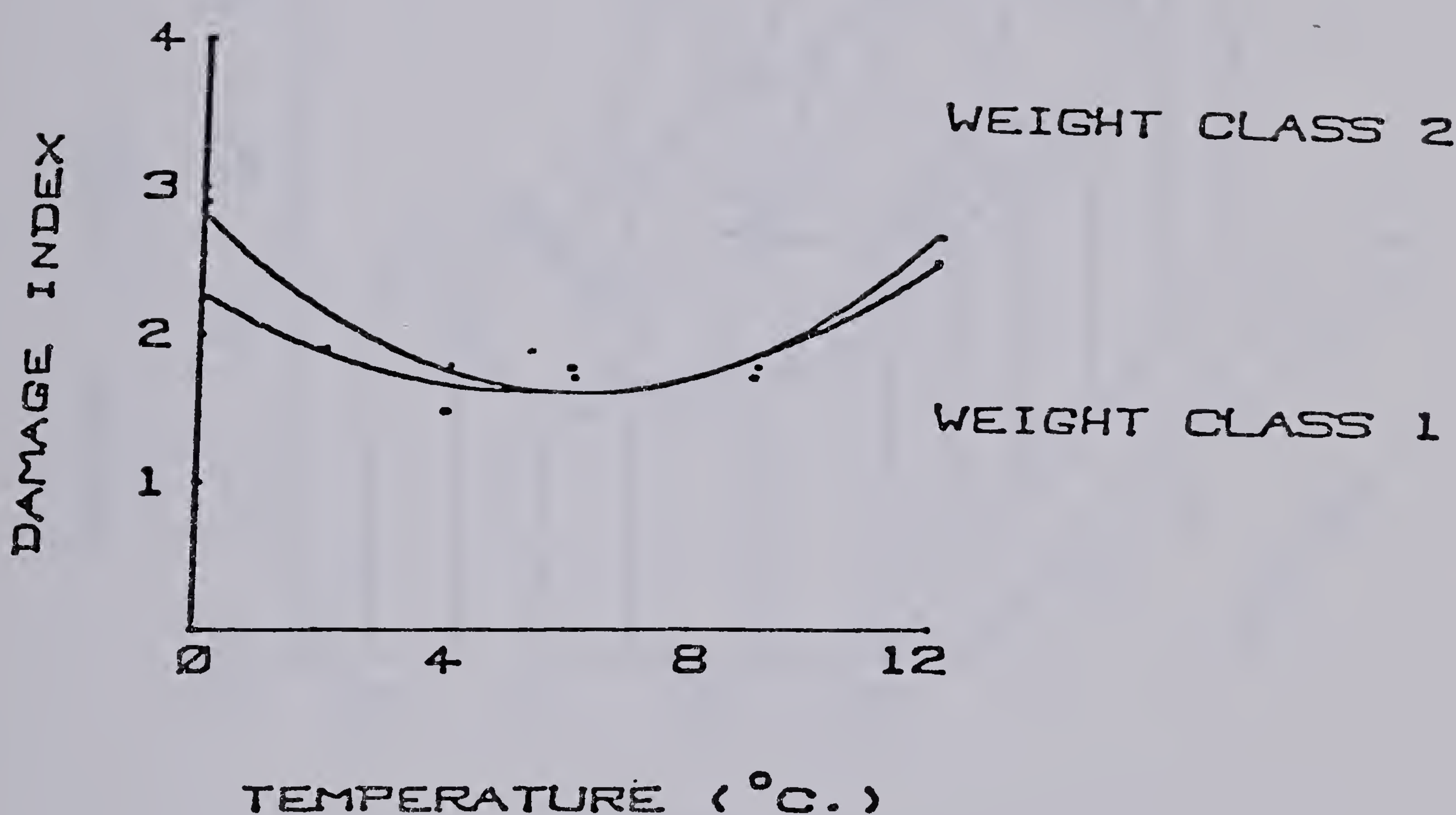

Fig 9. Temperature Vs. Damage Index for Weight Classes 1 (227g) & 2 (340g) at 450mm Drop height

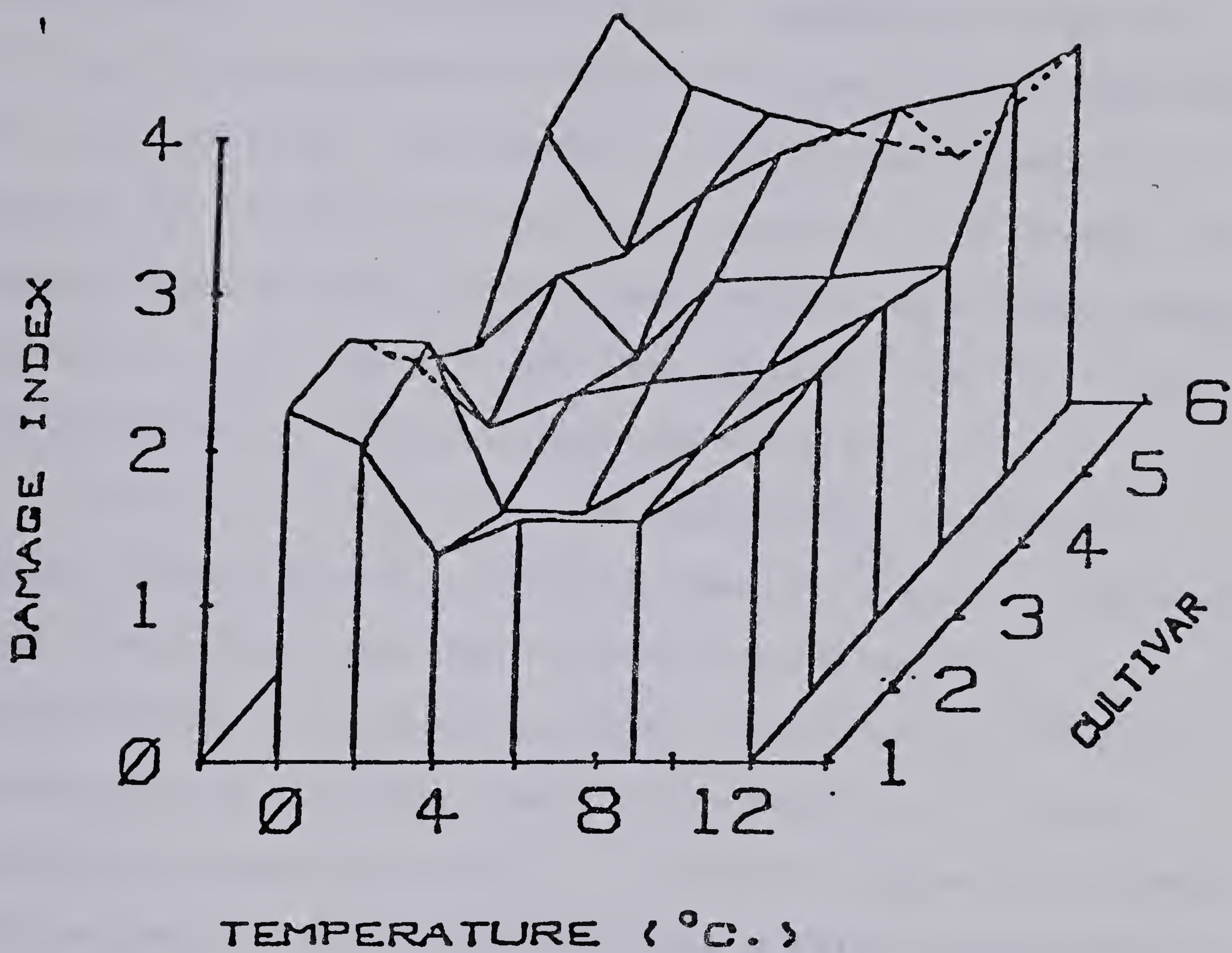

Fig. 10. Temperature - Cultivar Interaction for Damage Index for cultivar 1(Netted Gem), 2(Norgold Russet), 3(Norchip), 4(Kennebec), 5(Warba) and 6(Norland).

Norland. A better estimate of the optimum temperature is obtained by fitting best fit curves as noted previously. As in the prior example the parabolic function provided the greatest coefficient of determination for five cultivars (see table 8), the exception being Kennebec. As there is little to choose between the parabolic and linear functions for this cultivar, the parabolic function was used to fit curves for all the cultivars (see figure 11). Although the damage index and the optimum temperature for minimum damage varied, five of the six cultivars showed a similar response; the difference is the optimum temperature.

Figure 12 illustrates the Temperature - Cultivar - Weight class interaction and it does not appear to indicate that the weight class may have different optimum temperatures within each cultivar. To arrive at a better estimate of the optimum temperature the best fit curve technique (noted previously) is used in figure 13. As before the parabolic function provided the greatest coefficient of determination (see table 9) for four of the cultivars with the exception of Kennebec(V^4) and Warba(V^5). For example the indicated temperature for Norgold Russet(V^2) is 7°C for both the weight clases and for Netted Gem(V^1) it is 8°C and 7°C for both the sizes.

The statistical significance of this second order interaction appear to stem from a reponse of the damage index with respect to minimum damage for the cultivars Kennebec(V^4) and Warba(V^5). Power functions (see table 9)

Table 8: COEFFICIENTS OF DETERMINATION r^2 FOR THE TEMPERATURE - CULTIVAR INTERACTION

Cultivar	Linear	Power	Exponential	Parabolic
Netted Gem	.07	.35	.05	.84
Norgold Russ.	.04	.22	.02	.76
Norchip	.48	.01	.46	.82
Kennebec	.43	.34	.41	.43
Warba	.47	.01	.42	.61
Norland	.07	.42	.07	.90

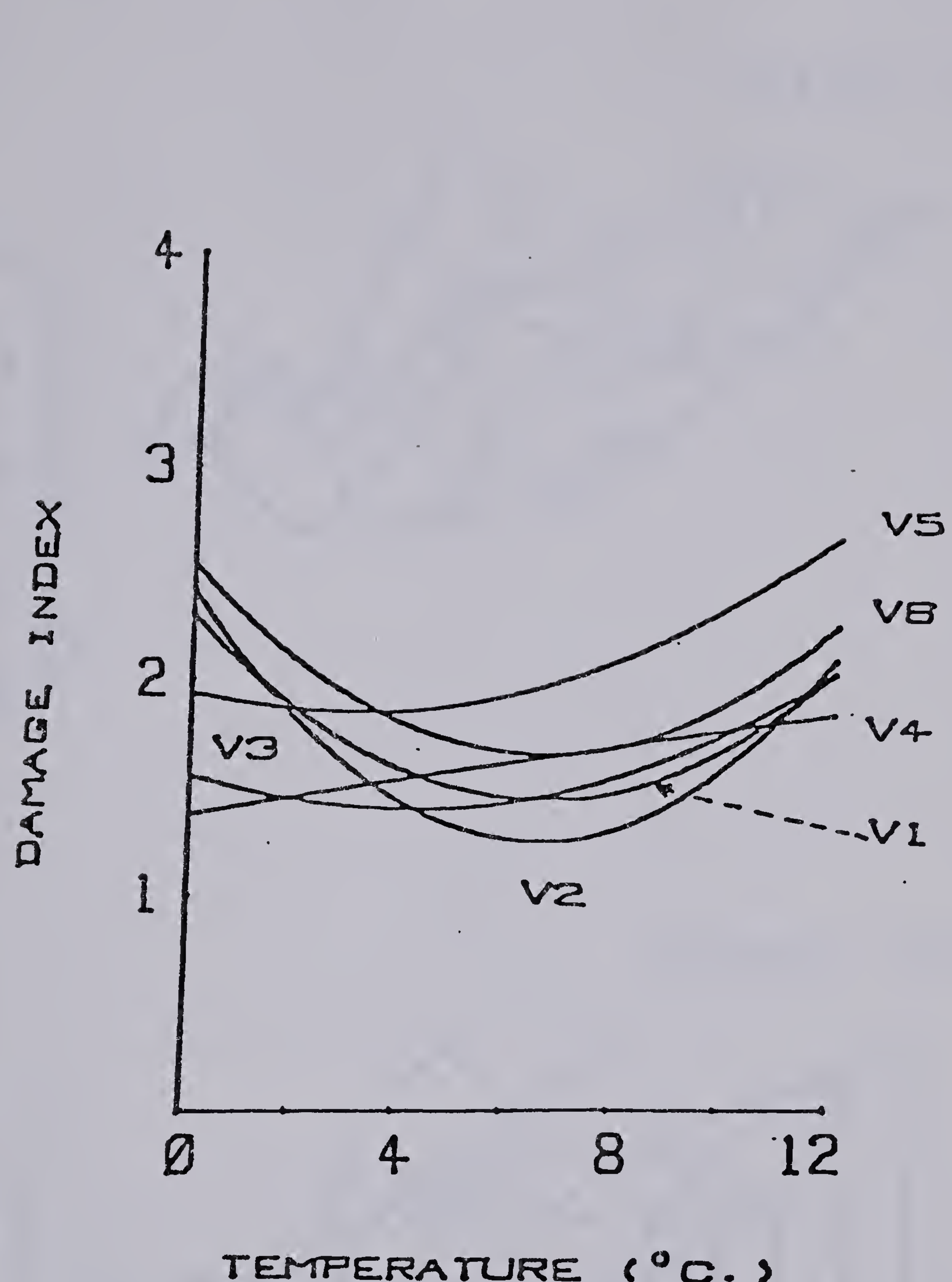

Fig. 11. Temperature Vs Damage Index for Cultivars 1(Netted Gem), 2(Norgold Russet), 3(Norchip), 4(Kennebec), 5(Warba) and 6(Norland).

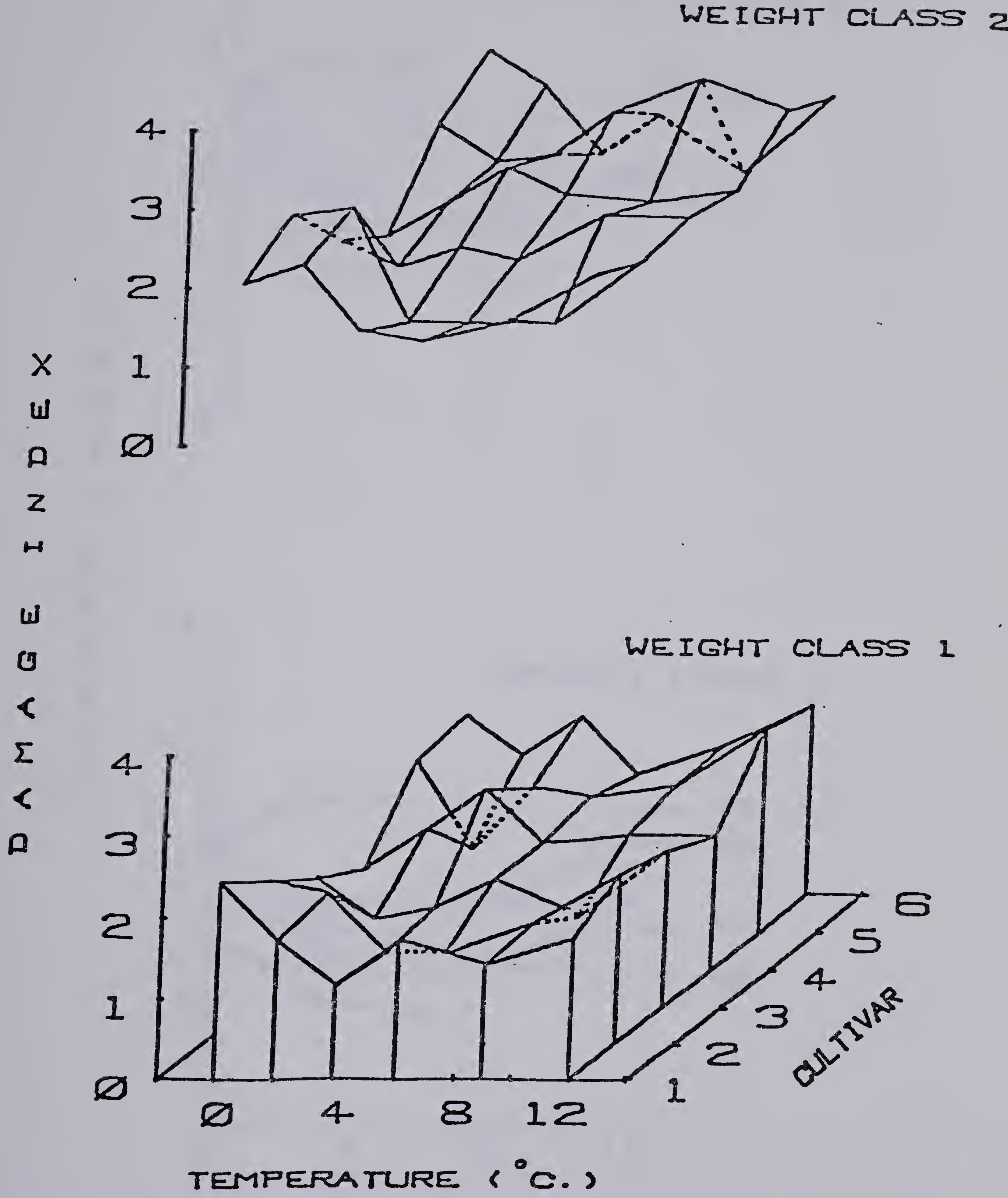

Fig. 12. Temperature - Cultivar - Weight Class Interaction for Damage Index where cultivar 1 is Netted gem, 2 is Norgold russet, 3 is Norchip, 4 is Kennebec, 5 is Warba and 6 is Norland.

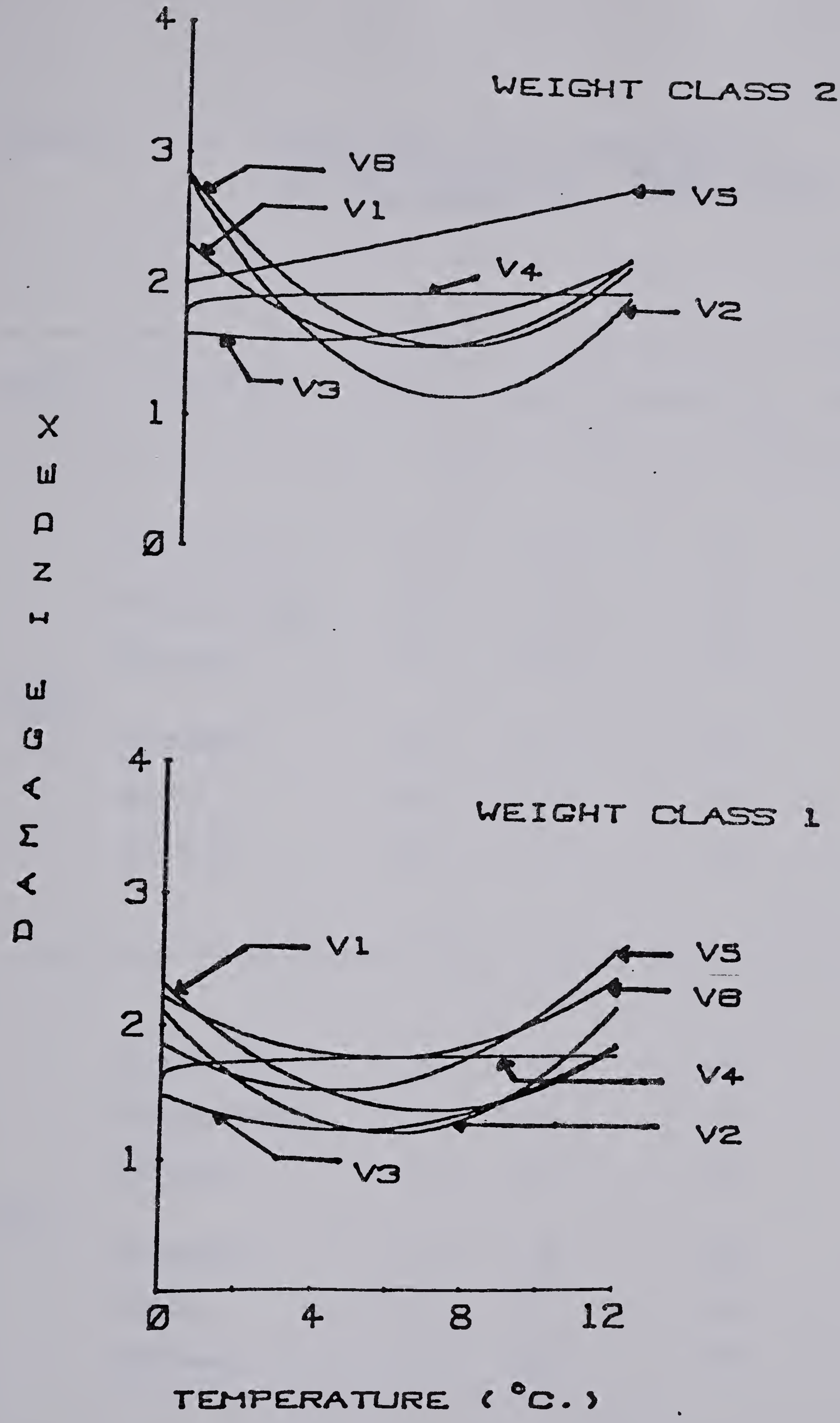

Fig. 13. Temperature - Cultivar - Weight Class Interaction for Cultivars 1(Netted Gem), 2(Norgold Russet), 3(Norchip), 4(Kennebec), 5(Warba) and 6(Norland).

Table 9: COEFFICIENT OF DETERMINATION r^2 FOR THE TEMPERATURE - WEIGHT CLASS - CULTIVAR INTERACTION

Weight	Cultivar	Linear	Power	Exponential	Parabolic
227g	Netted Gem	.16	.57	.10	.68
	Norgold Russ.	.00	.17	.00	.88
	Norchip	.18	.04	.14	.52
	Kennebec	.04	.57	.07	.34
	Warba	.28	.05	.25	.60
	Norland	.03	.10	.02	.49
340g	Netted Gem	.00	.07	.00	.63
	Norgold Russ.	.20	.28	.16	.76
	Norchip	.55	.00	.52	.69
	Kennebec	.28	.79	.32	.56
	Warba	.47	.01	.46	.47
	Norland	.19	.35	.16	.73

provided the highest coefficient of determination for both the weight classes for the cultivar Kennebec and consequently (fig. 14) does not indicate an optimum temperature with respect to minimum damage in either weight class. Unlike Kennebec, the smaller weight class of Warba indicates an optimum temperature range between 4° and 6°C (see fig. 15). As for the larger weight class there was little to choose between linear and parabolic functions (table 9) and a parabolic function was used to fit a curve for this weight class. This parabolic curve indicates that an optimum temperature may lie beyond the temperature range selected for this study.

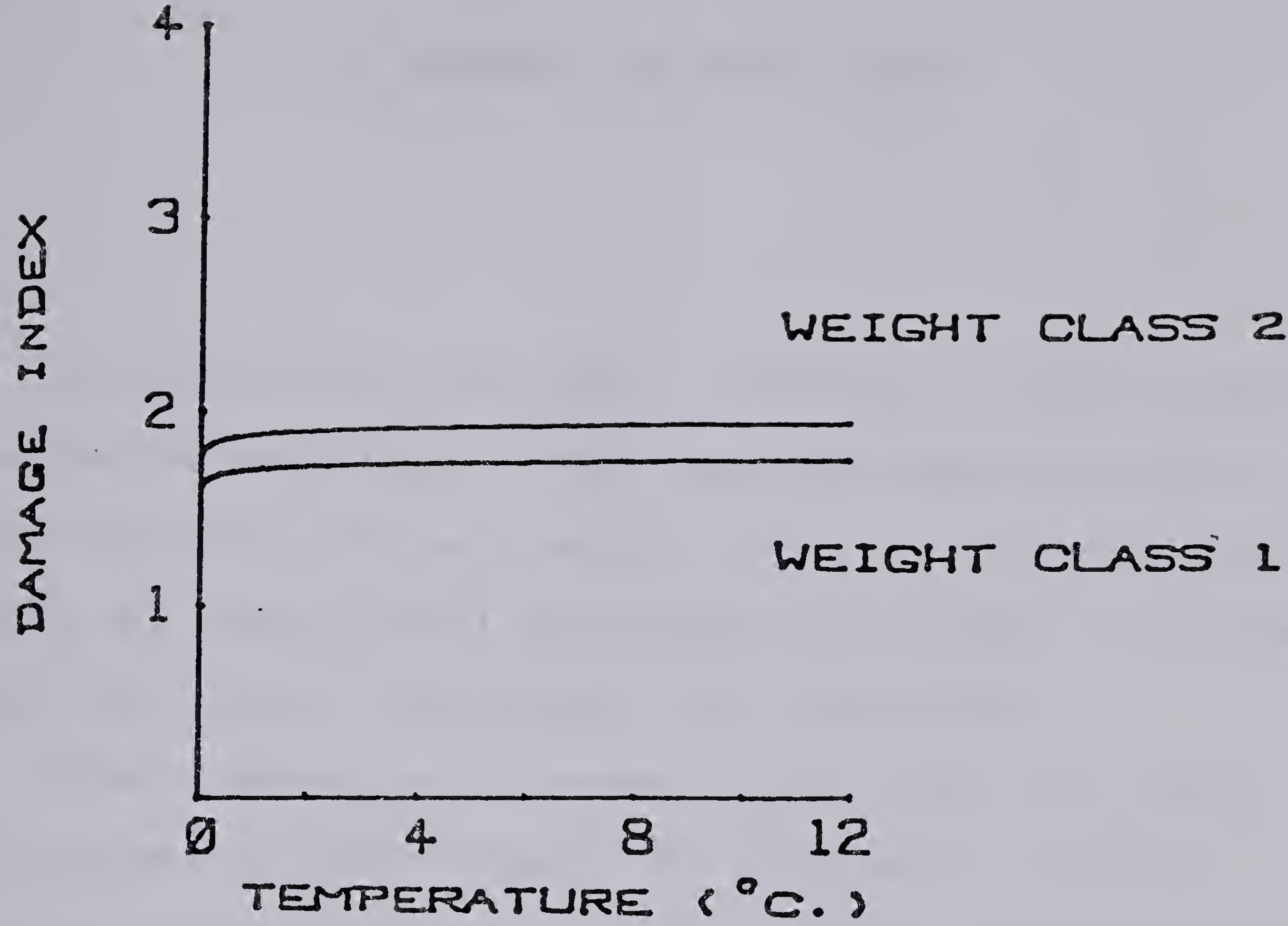

Fig. 14. Temperature Vs Damage Index for the Cultivar Kennebec

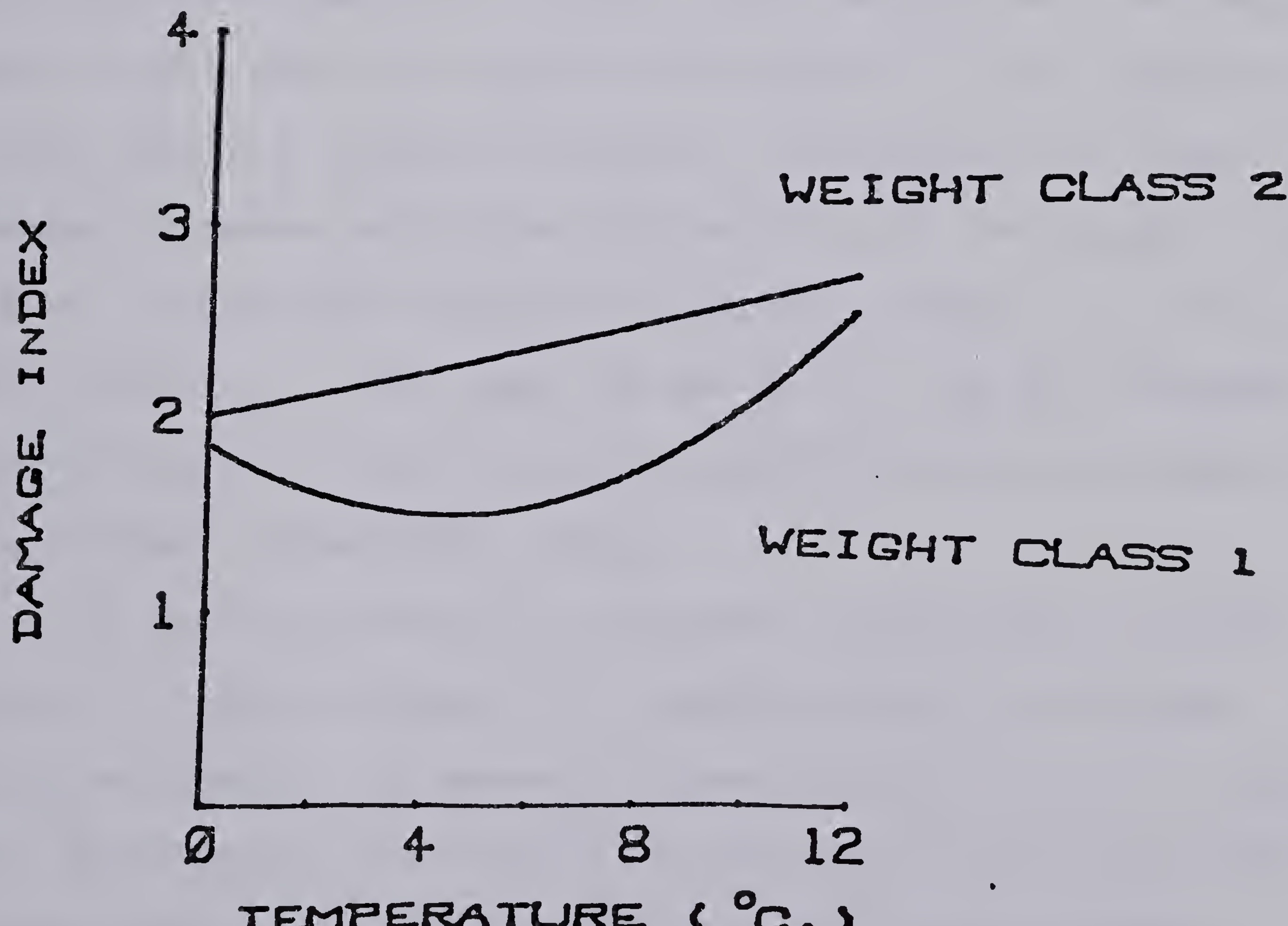

Fig. 15. Temperature Vs Damage Index for the Cultivar Warba

5. SUMMARY AND CONCLUSIONS

The maturity of the tuber as reported in other studies, affected the resistance of the tuber to impact and less damage occurred with more mature tubers. An optimum maturity or even an indication of an optimum with respect to minimum damage was beyond the scope of this experiment.

Tuber temperature at harvest is an important factor with respect to tuber damage. The experimental results indicate an optimum temperature for minimum damage between 4° to 6°C (table 6). This main effect is similar to that obtained by McRae et.al. (32). Likewise the main response to drop height and the weight of the tuber is also comparable to the results reported by other investigators as tuber damage increased with the drop height and the weight of the tuber. On the other hand the accepted concept of limiting drop heights to less than 150 mm (6 in.) can be increased considerably if the harvesting operations are performed in the optimum temperature range.

Of the six cultivars included in this study, Netted Gem(V^1), Norgold Russet(V^2), and Norland(V^6) indicated minimum damage at a harvest temperature of 5° to 7°C (Fig. 11). Norchip(V^3) and Warba(V^5) with the exception of the larger tubers for the latter indicated minimum damage between 2° to 5°C (Fig. 13). Kennebec(V^4) is the only

cultivar that did not indicate an optimum temperature with respect to minimum damage. Although the larger tubers were more susceptible to damage than the smaller tubers the response to temperature did not seem to be influenced by the weight of the tuber with respect to minimum damage.

6. RECOMMENDATIONS

As a result of this study individual temperature controlled climate chambers are recommended for future studies to simulate tuber temperature at harvest. Some of the interactions: for example the temperature - maturity interaction could not be included in this study for the lack of this equipment.

An index combining the drop height, harvest temperature and tuber damage should be developed to recommend a maximum permissible drop height without a loss of grade and excessive damage.

It is also imperative that some of the other popular Alberta grown cultivars like Red Pontiac, Viking and Batoche be included in future studies.

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APPENDIX

*NOTATION** *P V T H W*	*LENGTH* *mm*	*BREADTH* *mm*	*DEPTH* *mm*	*DAMAGE* *INDEX*	*%* *DAMAGE*
1 1 1 1 1	38.3	11.0	6.7	3.0	1.35
1 1 1 1 2	37.3	13.3	11.3	3.0	1.80
1 1 1 2 1	35.3	10.7	5.0	3.0	0.90
1 1 1 2 2	29.7	11.7	5.7	3.0	0.62
1 1 1 3 1	21.7	3.7	1.7	2.0	0.06
1 1 1 3 2	10.3	2.0	1.3	0.7	0.01
1 1 2 1 1	30.3	14.3	8.0	2.7	1.67
1 1 2 1 2	44.3	16.3	6.7	2.7	1.54
1 1 2 2 1	23.3	5.7	4.0	2.0	0.25
1 1 2 2 2	34.3	14.7	7.0	2.7	1.12
1 1 2 3 1	7.0	0.7	0.3	0.3	0.0
1 1 2 3 2	11.7	5.3	1.3	1.3	0.03
1 1 3 1 1	43.0	6.7	4.0	3.0	0.55
1 1 3 1 2	50.3	6.7	4.3	2.7	0.46
1 1 3 2 1	6.3	3.7	2.0	0.7	0.02
1 1 3 2 2	12.0	3.7	1.7	1.0	0.02
1 1 3 3 1	3.7	2.3	1.3	0.7	0.0
1 1 3 3 2	15.0	8.0	3.7	1.0	0.14
1 1 4 1 1	38.7	10.3	7.0	2.7	1.34
1 1 4 1 2	37.0	6.3	3.0	2.7	0.22

1 1 4 2 1	13.0	6.7	1.0	1.3	0.04
1 1 4 2 2	4.3	3.7	1.3	0.7	0.01
1 1 4 3 1	27.7	10.7	6.0	2.3	0.85
1 1 4 3 2	21.7	6.3	0.7	0.7	0.03
1 1 5 1 1	25.3	7.3	4.3	2.7	0.39
1 1 5 1 2	17.3	3.0	2.3	2.0	0.04
1 1 5 2 1	13.7	3.3	2.0	1.3	0.04
1 1 5 2 2	17.3	5.3	3.7	1.3	0.11
1 1 5 3 1	13.7	3.7	0.3	0.3	0.01
1 1 5 3 2	8.7	2.7	2.0	0.7	0.02
1 1 6 1 1	39.0	7.7	6.0	2.7	0.86
1 1 6 1 2	36.0	9.3	7.0	3.0	0.75
1 1 6 2 1	38.7	5.7	6.3	2.7	0.67
1 1 6 2 2	39.3	11.7	8.3	3.0	1.22
1 1 6 3 1	0.0	0.0	0.0	0.0	0.0
1 1 6 3 2	6.7	2.7	1.3	0.7	0.01
1 2 1 1 1	34.0	12.7	10.7	2.7	1.98
1 2 1 1 2	49.3	14.0	12.0	3.0	2.50
1 2 1 2 1	48.3	32.3	18.7	3.3	12.59
1 2 1 2 2	38.7	10.0	5.0	2.3	0.58
1 2 1 3 1	6.0	1.0	0.3	0.3	0.0
1 2 1 3 2	25.7	8.0	4.3	2.3	0.27
1 2 2 1 1	46.3	13.7	8.7	3.0	2.37
1 2 2 1 2	42.0	15.0	12.3	3.0	2.35
1 2 2 2 1	22.3	8.0	6.7	2.7	0.51
1 2 2 2 2	32.7	14.7	7.3	2.7	1.06
1 2 2 3 1	19.7	4.0	0.7	0.7	0.02

1 2 2 3 2	26.7	12.3	8.3	2.7	0.83
1 2 3 1 1	25.3	8.0	4.7	2.0	0.41
1 2 3 1 2	46.3	19.3	15.0	3.0	4.06
1 2 3 2 1	18.3	5.3	3.3	1.3	0.14
1 2 3 2 2	20.7	6.3	2.7	1.0	0.11
1 2 3 3 1	0.0	0.0	0.0	0.0	0.0
1 2 3 3 2	12.7	0.7	0.3	0.3	0.0
1 2 4 1 1	25.0	7.0	4.3	1.7	0.33
1 2 4 1 2	26.0	6.3	4.7	2.0	0.23
1 2 4 2 1	34.0	5.3	2.0	1.7	0.16
1 2 4 2 2	9.3	2.0	1.7	0.7	0.01
1 2 4 3 1	0.0	0.0	0.0	0.0	0.0
1 2 4 3 2	10.0	4.0	2.7	1.0	0.03
1 2 5 1 1	21.0	10.3	9.3	2.0	0.88
1 2 5 1 2	54.3	14.3	13.0	3.0	3.06
1 2 5 2 1	25.0	3.5	4.5	2.7	33.45
1 2 5 2 2	50.7	11.7	8.7	3.0	2.21
1 2 5 3 1	15.0	1.3	1.0	1.0	0.01
1 2 5 3 2	8.7	2.7	1.3	0.0	0.01
1 2 6 1 1	41.0	20.0	14.7	3.0	5.19
1 2 6 1 2	38.0	17.3	8.7	2.7	1.72
1 2 6 2 1	29.0	10.0	6.7	2.3	0.83
1 2 6 2 2	30.7	7.0	3.7	2.3	0.24
1 2 6 3 1	20.0	5.7	3.0	1.7	0.15
1 2 6 3 2	5.0	4.7	1.0	1.0	0.01
1 3 1 1 1	36.7	10.0	8.3	2.7	1.45
1 3 1 1 2	21.7	10.0	8.3	2.3	0.52

1 3 1 2 1	23.3	6.0	3.7	2.0	0.24
1 3 1 2 2	40.0	11.7	10.0	3.0	1.34
1 3 1 3 1	0.0	0.0	0.0	0.0	0.0
1 3 1 3 2	10.0	3.3	3.3	0.7	0.03
1 3 2 1 1	29.0	11.0	7.0	2.0	1.06
1 3 2 1 2	21.7	8.3	8.3	1.7	0.43
1 3 2 2 1	13.3	4.3	3.7	1.3	0.10
1 3 2 2 2	18.3	4.3	3.7	1.7	0.08
1 3 2 3 1	0.0	0.0	0.0	0.0	0.0
1 3 2 3 2	8.3	1.0	0.7	0.7	0.0
1 3 3 1 1	30.0	8.7	8.7	2.3	1.07
1 3 3 1 2	36.7	11.7	11.7	3.0	1.43
1 3 3 2 1	3.3	0.3	0.3	0.3	0.0
1 3 3 2 2	16.7	5.0	4.7	1.7	0.11
1 3 3 3 1	11.7	1.0	1.0	1.0	0.0
1 3 3 3 2	3.3	0.3	0.3	0.3	0.0
1 3 4 1 1	30.0	9.3	10.0	3.0	1.33
1 3 4 1 2	40.0	24.7	19.0	3.7	5.39
1 3 4 2 1	35.0	15.7	11.3	3.0	2.95
1 3 4 2 2	12.3	1.7	7.3	1.3	0.04
1 3 4 3 1	3.7	0.3	0.3	0.0	0.0
1 3 4 3 2	0.0	0.0	0.0	0.0	0.0
1 3 5 1 1	19.0	9.5	11.5	3.3	33.99
1 3 5 1 2	41.3	13.7	8.7	3.0	1.41
1 3 5 2 1	5.3	1.0	1.0	0.0	0.0
1 3 5 2 2	46.3	13.3	8.7	2.7	1.54
1 3 5 3 1	3.3	0.3	0.3	0.3	0.0

1 3 5 3 2	44.7	8.0	5.0	2.0	0.51
1 3 6 1 1	32.3	12.7	8.0	3.0	1.56
1 3 6 1 2	49.3	12.3	10.7	3.0	1.86
1 3 6 2 1	20.0	10.0	8.0	3.7	33.84
1 3 6 2 2	20.7	8.0	7.0	2.7	0.33
1 3 6 3 1	13.7	1.0	0.7	0.7	0.0
1 3 6 3 2	15.3	8.7	3.3	1.7	0.13
1 4 1 1 1	30.3	6.7	5.0	2.0	0.48
1 4 1 1 2	10.0	4.3	2.3	1.0	0.03
1 4 1 2 1	25.3	4.7	3.3	1.3	0.19
1 4 1 2 2	30.0	6.0	3.5	3.0	21.41
1 4 1 3 1	6.7	0.3	0.3	0.3	0.0
1 4 1 3 2	0.0	0.0	0.0	0.0	0.0
1 4 2 1 1	38.3	8.3	8.7	2.3	1.33
1 4 2 1 2	40.7	13.0	10.7	2.7	1.72
1 4 2 2 1	59.5	15.0	13.0	3.7	55.90
1 4 2 2 2	15.3	9.0	7.7	2.0	0.32
1 4 2 3 1	0.0	0.0	0.0	0.0	0.0
1 4 2 3 2	6.0	0.3	0.3	0.3	0.0
1 4 3 1 1	41.7	15.3	16.0	3.3	4.89
1 4 3 1 2	59.3	17.0	14.7	3.0	4.52
1 4 3 2 1	31.0	10.3	7.3	2.7	1.12
1 4 3 2 2	29.3	9.0	8.3	2.7	0.67
1 4 3 3 1	20.3	8.7	1.3	1.3	0.11
1 4 3 3 2	10.0	4.7	1.0	1.0	0.02
1 4 4 1 1	28.3	13.7	8.0	2.7	1.48
1 4 4 1 2	53.5	14.0	9.0	3.3	34.71

1 4 4 2 1	18.3	6.7	4.3	2.0	0.25
1 4 4 2 2	12.0	6.0	4.7	2.0	0.10
1 4 4 3 1	3.3	0.3	0.3	0.3	0.0
1 4 4 3 2	10.0	3.7	2.7	1.0	0.03
1 4 5 1 1	39.3	11.7	9.7	3.0	2.12
1 4 5 1 2	42.0	12.0	10.0	3.7	34.36
1 4 5 2 1	17.0	5.0	4.0	1.7	0.16
1 4 5 2 2	12.3	3.7	3.3	1.0	0.05
1 4 5 3 1	13.7	2.7	1.3	1.0	0.02
1 4 5 3 2	15.3	6.7	2.7	1.0	0.08
1 4 6 1 1	25.0	9.3	7.0	3.0	0.78
1 4 6 1 2	49.7	15.0	11.7	3.0	2.65
1 4 6 2 1	17.7	5.7	2.7	2.0	0.13
1 4 6 2 2	35.3	10.7	8.3	3.0	0.96
1 4 6 3 1	18.3	14.3	9.0	1.0	1.13
1 4 6 3 2	5.0	5.0	5.0	1.0	0.04
1 5 1 1 1	46.7	21.7	22.7	3.0	10.39
1 5 1 1 2	50.0	18.3	23.3	2.7	6.43
1 5 1 2 1	33.3	13.3	8.3	2.7	1.68
1 5 1 2 2	35.0	15.0	20.0	4.3	67.72
1 5 1 3 1	16.7	6.7	5.3	0.7	0.27
1 5 1 3 2	13.3	1.0	1.0	0.0	0.0
1 5 2 1 1	16.7	6.7	2.3	1.0	0.12
1 5 2 1 2	45.0	25.0	16.7	3.3	5.64
1 5 2 2 1	0.0	0.0	0.0	0.0	0.0
1 5 2 2 2	48.3	8.3	20.0	2.3	2.42
1 5 2 3 1	13.3	3.3	3.3	1.0	0.07

1 5 2 3 2	13.3	1.3	1.3	0.3	0.01
1 5 3 1 1	43.3	10.0	16.7	3.3	3.27
1 5 3 1 2	58.3	16.7	11.7	3.0	3.41
1 5 3 2 1	41.7	8.3	6.7	2.7	1.05
1 5 3 2 2	20.0	15.0	12.5	3.3	34.08
1 5 3 3 1	0.0	0.0	0.0	0.0	0.0
1 5 3 3 2	3.3	1.7	1.7	0.3	0.0
1 5 4 1 1	40.0	15.0	15.0	3.3	4.08
1 5 4 1 2	40.0	16.7	15.0	3.0	3.01
1 5 4 2 1	35.0	10.3	8.7	2.0	1.42
1 5 4 2 2	53.3	10.0	8.3	3.0	1.33
1 5 4 3 1	1.0	1.0	1.0	1.0	0.0
1 5 4 3 2	46.7	13.3	5.0	3.0	0.93
1 5 5 1 1	41.7	20.0	13.3	4.0	5.03
1 5 5 1 2	38.3	20.0	16.7	4.0	3.84
1 5 5 2 1	31.7	16.7	8.3	2.7	1.99
1 5 5 2 2	45.0	20.0	15.0	3.3	4.06
1 5 5 3 1	16.7	0.7	0.7	0.0	0.0
1 5 5 3 2	48.3	20.0	13.3	3.3	3.87
1 5 6 1 1	41.7	13.3	13.3	3.7	3.36
1 5 6 1 2	53.3	36.7	10.0	3.7	5.88
1 5 6 2 1	23.3	10.0	8.3	2.7	0.88
1 5 6 2 2	35.0	6.7	6.7	2.7	0.47
1 5 6 3 1	6.7	3.3	1.7	0.7	0.02
1 5 6 3 2	23.3	8.3	6.7	1.3	0.39
1 6 1 1 1	30.0	10.0	7.5	3.3	34.03
1 6 1 1 2	52.5	20.0	10.0	3.7	35.53

1 6 1 2 1	36.7	6.7	6.7	2.0	0.76
1 6 1 2 2	30.0	7.5	5.0	3.3	33.57
1 6 1 3 1	23.3	8.0	7.0	2.3	0.61
1 6 1 3 2	25.0	6.7	9.3	2.3	0.49
1 6 2 1 1	45.0	16.7	10.0	3.0	3.50
1 6 2 1 2	51.7	13.3	10.0	3.0	2.17
1 6 2 2 1	41.7	11.0	8.3	2.7	1.79
1 6 2 2 2	28.3	6.0	5.0	2.0	0.27
1 6 2 3 1	6.7	0.3	0.3	0.3	0.0
1 6 2 3 2	28.3	5.3	4.3	2.3	0.20
1 6 3 1 1	50.0	10.0	10.0	3.7	34.89
1 6 3 1 2	53.3	11.7	10.0	3.0	1.96
1 6 3 2 1	36.7	5.3	5.3	2.0	0.49
1 6 3 2 2	31.7	3.7	3.7	1.7	0.14
1 6 3 3 1	23.3	14.3	7.0	1.7	1.09
1 6 3 3 2	10.0	3.3	1.7	0.7	0.02
1 6 4 1 1	38.3	10.0	6.7	3.0	1.20
1 6 4 1 2	65.0	15.0	10.0	3.7	3.07
1 6 4 2 1	20.0	6.0	2.3	2.0	0.13
1 6 4 2 2	46.7	10.0	8.3	3.0	1.22
1 6 4 3 1	7.7	1.0	1.0	0.0	0.0
1 6 4 3 2	12.7	3.3	2.3	0.3	0.03
1 6 5 1 1	6.7	0.3	0.3	0.3	0.0
1 6 5 1 2	47.5	12.5	7.5	4.0	34.27
1 6 5 2 1	41.7	13.3	10.0	3.3	2.60
1 6 5 2 2	11.7	1.7	1.7	0.7	0.01
1 6 5 3 1	21.7	8.3	4.3	2.0	0.36

1 6 5 3 2	0.0	0.0	0.0	0.0	0.0
1 6 6 1 1	55.0	20.0	16.7	3.7	8.57
1 6 6 1 2	60.0	25.0	16.7	3.7	7.87
1 6 6 2 1	30.0	25.0	12.5	4.0	36.25
1 6 6 2 2	40.0	13.3	11.7	3.3	1.96
1 6 6 3 1	0.0	0.0	0.0	1.7	33.33
1 6 6 3 2	10.0	1.7	0.3	0.7	0.0
2 1 1 1 1	34.7	12.7	7.3	3.0	1.54
2 1 1 1 2	25.0	13.3	11.3	3.0	1.21
2 1 1 2 1	33.0	9.3	5.3	2.3	0.79
2 1 1 2 2	28.0	10.3	5.0	2.0	0.46
2 1 1 3 1	19.3	3.7	1.3	1.3	0.04
2 1 1 3 2	17.3	5.3	0.7	0.7	0.02
2 1 2 1 1	32.7	14.3	6.0	3.0	1.35
2 1 2 1 2	39.7	19.3	9.3	3.0	2.28
2 1 2 2 1	22.0	6.7	3.3	2.0	0.23
2 1 2 2 2	28.3	13.0	6.7	3.0	0.78
2 1 2 3 1	8.0	1.0	0.3	0.3	0.0
2 1 2 3 2	13.0	5.0	3.0	1.3	0.06
2 1 3 1 1	29.3	6.3	6.3	2.0	0.57
2 1 3 1 2	46.7	7.3	8.3	2.0	0.91
2 1 3 2 1	15.7	4.7	0.7	0.7	0.02
2 1 3 2 2	19.7	6.3	2.3	1.3	0.09
2 1 3 3 1	0.0	0.0	0.0	0.0	0.0
2 1 3 3 2	11.7	7.7	1.0	1.0	0.03
2 1 4 1 1	27.3	8.7	5.0	2.0	0.57
2 1 4 1 2	39.0	8.7	5.7	2.0	0.61

2 1 4 2 1	24.0	8.3	1.7	1.3	0.16
2 1 4 2 2	31.3	8.0	2.0	1.3	0.16
2 1 4 3 1	15.0	3.7	0.7	0.7	0.02
2 1 4 3 2	30.3	8.0	1.0	1.0	0.08
2 1 5 1 1	25.0	9.0	5.3	2.3	0.58
2 1 5 1 2	24.7	9.3	9.7	3.0	0.71
2 1 5 2 1	20.7	9.0	5.0	1.7	0.45
2 1 5 2 2	25.3	6.3	4.0	2.0	0.20
2 1 5 3 1	10.0	2.7	0.3	0.3	0.0
2 1 5 3 2	16.7	5.0	2.3	1.0	1.50
2 1 6 1 1	33.3	7.7	5.3	2.7	0.65
2 1 6 1 2	34.0	12.0	7.0	3.0	0.91
2 1 6 2 1	28.0	13.3	6.7	2.3	1.19
2 1 6 2 2	31.3	9.0	3.7	2.0	0.33
2 1 6 3 1	7.0	1.0	0.3	0.3	0.0
2 1 6 3 2	19.0	8.7	6.3	2.0	0.33
2 2 1 1 1	25.7	10.0	10.0	2.7	1.11
2 2 1 1 2	51.3	14.0	7.3	3.0	1.59
2 2 1 2 1	43.3	13.0	9.3	3.0	2.27
2 2 1 2 2	39.0	14.3	10.0	3.0	1.69
2 2 1 3 1	0.0	0.0	0.0	0.0	0.0
2 2 1 3 2	31.3	9.7	5.0	1.3	0.06
2 2 2 1 1	37.3	11.7	8.0	2.7	1.50
2 2 2 1 2	36.7	9.0	7.3	3.0	0.73
2 2 2 2 1	21.7	12.7	7.0	2.0	0.83
2 2 2 2 2	30.0	12.3	9.3	2.0	1.04
2 2 2 3 1	0.0	0.0	0.0	0.0	0.0

2 2 2 3 2	23.7	10.0	9.7	2.3	0.69
2 2 3 1 1	16.0	10.0	6.3	2.0	0.44
2 2 3 1 2	42.0	15.0	9.3	2.3	1.78
2 2 3 2 1	24.3	9.7	3.3	1.3	0.34
2 2 3 2 2	4.7	3.3	0.3	0.3	0.0
2 2 3 3 1	0.0	0.0	0.0	0.0	0.0
2 2 3 3 2	0.0	0.0	0.0	0.0	0.0
2 2 4 1 1	28.3	10.3	9.0	2.0	1.14
2 2 4 1 2	31.0	10.3	10.0	2.0	0.97
2 2 4 2 1	24.7	8.7	2.7	1.3	0.25
2 2 4 2 2	27.3	10.7	1.0	1.0	0.09
2 2 4 3 1	0.0	0.0	0.0	0.0	0.0
2 2 4 3 2	8.0	3.3	0.3	0.3	0.0
2 2 5 1 1	23.7	9.3	5.3	1.7	0.51
2 2 5 1 2	39.7	9.7	7.7	2.0	0.89
2 2 5 2 1	24.0	6.0	3.3	1.3	0.21
2 2 5 2 2	38.7	13.0	5.3	2.0	0.81
2 2 5 3 1	8.0	3.3	0.3	0.3	0.0
2 2 5 3 2	0.0	0.0	0.0	0.0	0.0
2 2 6 1 1	42.3	15.0	13.3	2.7	3.66
2 2 6 1 2	37.7	12.3	7.3	2.7	1.03
2 2 6 2 1	29.7	14.0	9.7	2.0	1.73
2 2 6 2 2	26.3	9.3	8.3	2.3	0.62
2 2 6 3 1	23.0	9.7	1.0	1.0	0.09
2 2 6 3 2	12.7	9.3	1.0	1.0	0.04
2 3 1 1 1	48.3	10.7	9.3	2.7	2.28
2 3 1 1 2	21.3	10.0	4.3	2.0	0.26

2 3 1 2 1	27.3	7.3	5.0	2.0	0.47
2 3 1 2 2	30.3	9.0	5.7	2.3	0.45
2 3 1 3 1	3.3	0.3	0.3	0.0	0.0
2 3 1 3 2	3.3	0.3	0.3	0.0	0.0
2 3 2 1 1	12.0	6.7	3.0	1.0	0.11
2 3 2 1 2	37.3	9.7	8.0	2.0	0.83
2 3 2 2 1	24.3	8.7	4.7	2.0	0.47
2 3 2 2 2	34.7	7.3	5.0	2.0	0.36
2 3 2 3 1	0.0	0.0	0.0	0.0	0.0
2 3 2 3 2	8.0	2.0	0.3	0.3	0.0
2 3 3 1 1	23.0	10.7	8.0	2.3	0.93
2 3 3 1 2	31.3	7.3	5.3	2.0	0.35
2 3 3 2 1	17.3	8.7	1.0	1.0	0.07
2 3 3 2 2	27.3	9.7	6.7	2.0	0.0
2 3 3 3 1	3.7	2.0	0.3	0.3	0.0
2 3 3 3 2	17.3	8.0	1.0	1.0	0.04
2 3 4 1 1	20.3	8.0	5.0	1.7	0.38
2 3 4 1 2	29.3	13.0	11.3	2.3	1.24
2 3 4 2 1	26.0	16.3	4.3	1.7	0.87
2 3 4 2 2	15.7	6.0	6.0	1.3	0.16
2 3 4 3 1	0.0	0.0	0.0	0.0	0.0
2 3 4 3 2	7.0	2.7	0.3	0.3	0.0
2 3 5 1 1	19.3	9.3	9.0	2.7	0.77
2 3 5 1 2	38.0	11.3	6.0	2.0	0.74
2 3 5 2 1	2.7	2.0	0.3	0.3	0.0
2 3 5 2 2	30.0	9.0	5.0	1.7	0.39
2 3 5 3 1	0.0	0.0	0.0	0.0	0.0

2 3 5 3 2	23.0	10.0	2.0	1.3	0.13
2 3 6 1 1	30.0	8.3	8.0	2.3	0.95
2 3 6 1 2	33.0	7.7	7.3	2.0	0.53
2 3 6 2 1	18.3	9.7	4.7	2.0	0.39
2 3 6 2 2	23.0	8.7	9.3	2.7	0.53
2 3 6 3 1	0.0	0.0	0.0	0.0	0.0
2 3 6 3 2	7.3	4.7	0.7	0.7	0.01
2 4 1 1 1	31.0	10.7	8.3	2.0	1.32
2 4 1 1 2	27.3	8.7	6.0	2.0	0.43
2 4 1 2 1	26.7	12.7	2.7	1.3	0.43
2 4 1 2 2	43.0	10.0	9.0	2.0	1.18
2 4 1 3 1	7.3	1.3	0.3	0.3	0.0
2 4 1 3 2	0.0	0.0	0.0	0.0	0.0
2 4 2 1 1	33.7	10.0	7.7	2.0	1.23
2 4 2 1 2	48.7	12.7	10.0	3.0	1.88
2 4 2 2 1	28.7	10.0	8.7	2.0	1.19
2 4 2 2 2	22.0	12.0	7.7	2.3	0.62
2 4 2 3 1	4.0	1.0	0.3	0.3	0.0
2 4 2 3 2	4.7	1.3	0.3	0.3	0.0
2 4 3 1 1	27.3	12.0	10.3	3.0	1.62
2 4 3 1 2	48.7	17.3	13.0	3.0	3.35
2 4 3 2 1	24.0	8.0	6.7	2.3	0.61
2 4 3 2 2	30.3	12.0	10.3	2.7	1.15
2 4 3 3 1	15.0	5.3	0.7	0.7	0.02
2 4 3 3 2	11.0	6.7	1.0	1.0	0.02
2 4 4 1 1	26.3	12.7	7.0	2.7	1.11
2 4 4 1 2	46.0	10.0	7.7	3.0	1.08

2 4 4 2 1	17.3	6.7	5.3	1.7	0.30
2 4 4 2 2	10.3	3.3	3.0	2.0	0.03
2 4 4 3 1	0.0	0.0	0.0	0.0	0.0
2 4 4 3 2	0.0	0.0	0.0	0.0	0.0
2 4 5 1 1	28.7	9.0	7.3	2.3	0.90
2 4 5 1 2	45.3	10.3	7.3	3.0	1.05
2 4 5 2 1	15.3	4.0	3.3	1.7	0.10
2 4 5 2 2	23.7	8.7	4.3	2.0	0.27
2 4 5 3 1	7.0	1.0	0.3	0.3	0.0
2 4 5 3 2	11.3	2.0	0.3	0.3	0.0
2 4 6 1 1	15.3	5.0	5.3	2.0	0.20
2 4 6 1 2	21.3	8.3	4.7	2.0	0.25
2 4 6 2 1	16.3	7.3	2.7	1.7	0.15
2 4 6 2 2	26.7	8.0	4.7	2.3	0.31
2 4 6 3 1	10.3	1.3	0.3	0.3	0.0
2 4 6 3 2	11.7	4.0	0.7	0.7	0.01
2 5 1 1 1	38.0	16.7	15.3	2.7	4.40
2 5 1 1 2	42.3	16.3	16.0	2.3	3.32
2 5 1 2 1	28.7	6.0	7.0	2.3	0.54
2 5 1 2 2	34.5	23.0	24.0	3.7	37.15
2 5 1 3 1	16.0	10.3	4.7	1.3	0.35
2 5 1 3 2	13.3	23.7	4.0	0.7	0.38
2 5 2 1 1	0.3	0.7	0.3	0.0	0.0
2 5 2 1 2	38.3	11.3	24.0	2.0	3.14
2 5 2 2 1	7.3	4.3	3.0	0.7	0.05
2 5 2 2 2	10.0	1.0	0.7	0.3	0.0
2 5 2 3 1	33.3	10.0	9.7	3.3	1.46

2 5 2 3 2	20.0	13.3	6.0	2.7	0.48
2 5 3 1 1	43.0	7.3	8.0	2.7	1.14
2 5 3 1 2	51.0	18.7	8.0	2.7	2.29
2 5 3 2 1	39.7	8.7	6.0	2.0	0.93
2 5 3 2 2	21.3	11.3	6.7	2.3	0.48
2 5 3 3 1	0.0	0.0	0.0	0.0	0.0
2 5 3 3 2	0.3	1.3	0.3	0.0	0.0
2 5 4 1 1	25.3	14.7	7.7	1.7	1.29
2 5 4 1 2	17.3	12.7	7.3	2.0	0.48
2 5 4 2 1	32.7	4.7	6.7	1.7	0.46
2 5 4 2 2	48.7	8.0	5.7	2.0	0.66
2 5 4 3 1	16.7	8.0	1.0	0.3	0.06
2 5 4 3 2	30.7	9.7	7.7	2.0	0.68
2 5 5 1 1	33.3	15.7	8.7	2.7	2.05
2 5 5 1 2	34.3	10.3	5.7	3.0	0.60
2 5 5 2 1	16.0	4.0	2.0	1.7	0.06
2 5 5 2 2	28.7	6.7	5.3	2.0	0.31
2 5 5 3 1	16.3	0.7	0.7	0.0	0.0
2 5 5 3 2	35.7	14.0	8.0	2.0	1.20
2 5 6 1 1	45.3	18.3	15.0	4.0	5.65
2 5 6 1 2	45.3	31.3	7.7	3.3	3.27
2 5 6 2 1	30.0	14.3	9.7	3.0	1.89
2 5 6 2 2	35.3	11.7	7.0	3.0	0.87
2 5 6 3 1	15.7	8.3	4.0	1.3	0.24
2 5 6 3 2	24.7	7.7	6.7	1.3	0.38
2 6 1 1 1	26.7	9.0	7.0	2.3	0.79
2 6 1 1 2	38.0	9.7	8.0	2.3	0.93

2 6 1 2 1	34.3	7.0	4.0	1.7	0.45
2 6 1 2 2	32.7	8.0	5.0	3.0	0.41
2 6 1 3 1	26.3	8.3	5.7	1.7	0.58
2 6 1 3 2	32.0	5.3	4.3	2.0	0.23
2 6 2 1 1	35.0	16.7	8.7	2.3	2.36
2 6 2 1 2	38.7	16.3	9.0	3.0	1.79
2 6 2 2 1	35.0	9.7	6.7	2.0	1.06
2 6 2 2 2	29.7	5.3	5.7	2.0	0.28
2 6 2 3 1	0.0	0.0	0.0	0.0	0.0
2 6 2 3 2	34.3	4.0	4.3	1.7	0.19
2 6 3 1 1	52.0	12.0	5.7	3.0	1.65
2 6 3 1 2	37.3	8.7	4.0	2.0	0.41
2 6 3 2 1	20.3	9.3	3.7	1.0	0.33
2 6 3 2 2	26.3	4.7	3.0	1.7	0.12
2 6 3 3 1	28.0	10.0	4.3	2.0	0.57
2 6 3 3 2	0.0	0.0	0.0	0.0	0.0
2 6 4 1 1	27.3	7.3	3.3	2.0	0.31
2 6 4 1 2	46.7	11.7	9.3	2.7	1.60
2 6 4 2 1	20.0	9.7	5.3	2.0	0.48
2 6 4 2 2	41.0	8.7	6.3	2.3	0.71
2 6 4 3 1	0.0	0.0	0.0	0.0	0.0
2 6 4 3 2	3.7	0.3	0.3	0.0	0.0
2 6 5 1 1	27.0	8.0	4.3	1.7	0.44
2 6 5 1 2	40.3	9.3	5.3	3.0	0.63
2 6 5 2 1	17.7	8.0	4.0	2.3	0.27
2 6 5 2 2	0.0	0.0	0.0	0.0	0.0
2 6 5 3 1	17.7	5.0	4.3	1.7	0.18

2 6 5 3 2	0.0	0.0	0.0	0.0	0.0
2 6 6 1 1	37.0	13.0	5.0	2.3	1.12
2 6 6 1 2	59.3	20.7	7.3	3.0	2.83
2 6 6 2 1	23.3	12.3	4.0	2.0	0.54
2 6 6 2 2	40.0	15.7	7.7	3.0	1.51
2 6 6 3 1	4.7	2.7	0.3	0.7	0.0
2 6 6 3 2	0.0	0.0	0.0	0.0	0.0

* P is Harvest period, V is Cultivar, T is Temperature, H is Drop height and W is Weight class.